BRAZIL TAV PROJECT

Halcrow – Sinergia Consortium

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Part 1: Rail Operations

Final Report

SINERGIA
ESTUDOS E PROJETOS LTDA.

Halcrow

Brazil TAV

Halcrow - Sinergia Consortium

VOLUME 4

Rail Operations and Technology

Part 1: Rail Operations

Final Report

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

	Portuguese	English
AGETRANSP	Agência Reguladora dos Serviços Públicos Concedidos de Transportes Aquaviários, Ferroviários, Metroviários e de Rodovias do Estado do Rio de Janeiro	Regulatory agency of Concessioned Public Transport Services (Water, Rail, Metro, and Roads) of the state of Rio de Janeiro
ANAC	Agência Nacional de Aviação Civil	National Agency of Civil Aviation
ANTT	Agência Nacional de Transportes Terrestres	National Agency of Land (Ground) Transportation
ARTESP	Agência Reguladora de Transporte do Estado de São Paulo	Regulatory Transport Agency of the state of São Paulo
BCR		Benefit-Cost Ratio
BID	Banco Interamericano de Desenvolvimento	
BNDES	Banco Nacional de Desenvolvimento Economico e Social	
CAPEX		Capital Expenditure
CBD		Central Business District
CNT	Confederação Nacional do Transporte	National Confederation of Transport
CPTM	Companhia Paulista de Trens Metropolitanos	São Paulo Metropolitan Train Company
DENATRAN	Departamento Nacional de Trânsito	National Department of Transport
DER-SP	Departamento de Estradas de Rodagem do Estado de São Paulo	Department of Roads of the state of São Paulo
DETRO/RJ	Departamento de Transportes Rodoviários do Estado do Rio de Janeiro	Department of Road Transport in the State of Rio de Janeiro
DfT		UK Department for Transport
DNIT	Departamento Nacional de Infra-Estrutura de Transportes	National Department of Transport Infrastructure
EMBRATUR	Instituto Brasileiro de Turismo	Brazilian Institute of Tourism
FEA		Financial and Economic Appraisal
GDP		Gross Domestic Product
HS/HSR		High Speed Train/High Speed Rail
IBGE	Instituto Brasileiro de Geografia e Estatística	Brazilian Institute of Geography and Statistics
IBOPE	Instituto Brasileiro de Opinião Pública e Estatística	Brazilian Institute of Public Opinion and Statistics
INFRAERO	Empresa Brasileira de Infra-estrutura Aeroportuária	Airport Infrastructure Company of Brazil
IRR		Internal Rate of Return
MCA		Multi Criteria Analysis
NATA		New Approach to Transport Appraisal (UK Government)

	Portuguese	English
NPV		Net Present Value
OPEX		Operating Expenditure
PDDT-Vivo 2000/2020	Plano Diretor de Desenvolvimento dos Transportes 2000/2020	Transport Development Master Plan Study
PDTU-RMRJ	Plano Diretor de Transportes Urbanos da Região Metropolitana do Rio de Janeiro	Urban Transport Master Plan of the Metropolitan Region of Rio de Janeiro
PITU	O Plano Integrado de Transportes Urbanos para 2020	Integrated Urban Transport Plan for the Metropolitan Region of São Paulo
PPP		Public-Private Partnership
PV		Present Value
SEADE	Fundação Sistema Estadual de Análise de Dados de São Paulo	State Agency of Data Analysis of São Paulo
TAV	Trem de Alta Velocidade	High Speed Train
TOR		Terms of Reference
VfM		Value for Money
VOC		Vehicle Operating Costs
VOT		Value of Time
WEBTAG		The Web-based version of the UK DfT's Transport Appraisal Guidance

IMPORTANT NOTICE

THE CONSORTIUM DOES NOT ADVOCATE OR ENDORSE ANY SPECIFIC TYPE OF HIGH SPEED TRAIN OR TECHNOLOGY; WHEREVER POSSIBLE GENERIC HIGH SPEED RAILWAY SPECIFICATIONS AND STANDARDS HAVE BEEN USED TO DEVELOP ALL ASPECTS OF THIS STUDY INCLUDED IN THIS VOLUME. WHERE REFERENCE IS MADE TO A TYPE OF HIGH SPEED TRAIN OR TECHNOLOGY THIS DOES NOT IMPLY A PREFERENCE OR RECOMMENDATION ON THE PART OF THE CONSORTIUM. ALL JOURNEY TIMES ARE APPROXIMATE AND ARE BASED ON SIMULATIONS UNDERTAKEN BY THE CONSORTIUM. THEY ARE SUBJECT TO CHANGE DEPENDING ON THE FINAL ALIGNMENT ADOPTED.

1 Overview

1.1 Introduction to TAV Project

1.1.1 In 2008, the Inter-American Development Bank (IDB) commissioned Halcrow Group Ltd and Sinergia Estudos e Projetos LTDA (together the “Consortium”) to prepare a feasibility study for a high speed railway line, with a maximum line speed of 350km/h, over 511 kilometres connecting the cities of Rio de Janeiro, São Paulo and Campinas[1] in Brazil.

1.1.2 The Consortium has undertaken detailed studies summarised in the following volumes, as follows:

- Executive Summary;
- Volume 1: Demand and Revenue Forecasts;
- Volume 2: Alignment Studies;
- Volume 3: Finance and Economics Appraisal and Concessioning;
- Volume 4: Part 1- Rail Operations and Volume 4: Part 2 - Technology;
- Volume 5: TAV Capital Cost; and
- Volume 6: Real Estate.

1.1.3 Figure 1-1 shows the overall relationship between each study volume.

1.1.4 This volume presents the results of the work in Volume 4: Part 1 - Operations and is organised as follows:

- Chapter 2: Timetabling and Operations; and
- Chapter 3: Operating Cost estimates (OPEX).

1.2 Update on previous reports

1.2.1 Previous versions of this report considered the operation of an airport shuttle service connecting Campo de Marte and Guarulhos International Airport in São Paulo State. Initial estimates of demand for the airport shuttle service gave a forecast of 5.2 million passengers in 2008. This volume of passengers required a minimum of three trains per hour throughout the day which led to capacity issues between Campo de Marte and Guarulhos requiring a four-tack alignment. It has therefore been assumed that the demand expected between Campo de Marte and Guarulhos Airport is **NOT** included in the analysis presented here and is therefore not being covered by the proposed TAV. Although TAV will operate trains between these two stations, no passengers are assumed to board other than for long distance trips e.g. Campinas to Guarulhos International Airport.

1.2.2 As outlined in Volume 1, Section 3.7 there are two potential projects to provide a fixed rail link between Barra Funda and Guarulhos International Airport. Either of these projects could in theory provide sufficient capacity between central São Paulo and Guarulhos. This would then allow TAV to focus on serving long distance markets to the airport e.g. from Campinas and São José dos Campos to Guarulhos. As noted in Volume 1, it would also allow some internal flights between Galeão and Guarulhos to be replaced by rail, therefore freeing airport capacity.

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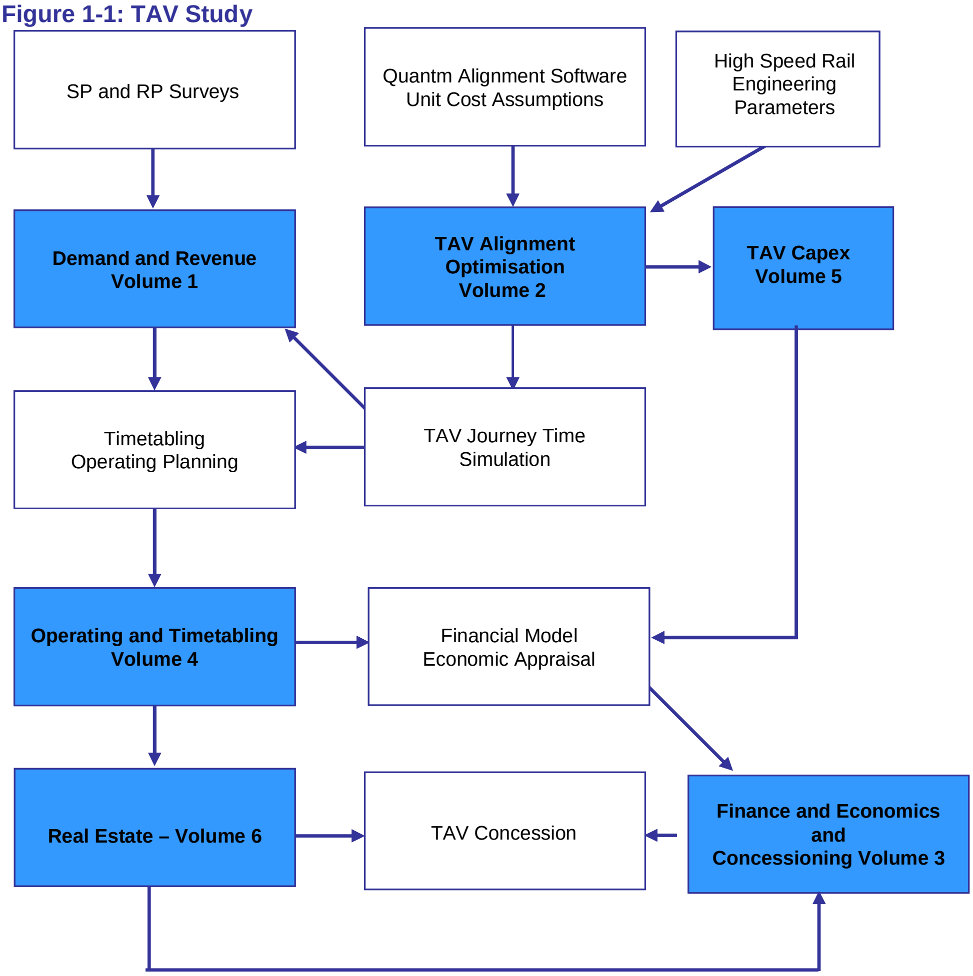
[1] Throughout this Executive Summary the project is referred to generically as TAV (*Trem de Alta Velocidade* in Portuguese)

1.2.3 Further details of the analysis undertaken for Guarulhos Airport are given in Appendix A.

Figure 1-1: TAV Study



1.3 Introduction to High Speed Rail

1.3.1 There is no single accepted definition of what constitutes a high speed railway but generally it refers to trains operating in excess of 200km/h. High speed rail is best suited to city pairs where their distance apart is less than 500km to 600km; beyond this distance, air travel becomes competitive and the relative market share of high speed rail declines.

1.3.2 A number of countries have invested in high speed rail services with Japan and France the leading proponents. Europe has developed an extensive high speed rail network with many thousands of kilometres of track now in operation with commercial speeds varying between 300km/h and 330 km/h, with 300km/h being the most common speed. The recently completed line between Madrid and Barcelona has the potential to run at a higher speed of 350km/h.

1.3.3 The principal characteristics of high speed rail are:

- competitive city centre to city centre journey times compared to air achieved by high speed running;
- very high train capacity with between 450 and 750 seats depending on configuration and length;
- new dedicated fully grade separated alignments operationally independent from existing conventional railway infrastructure, in most cases;

- frequent clock-face services with limited station stops to achieve competitive journey times;
- high levels of passenger comfort including executive and economy classes and catering services;
- high performance and punctuality; and
- conveniently located stations, often with better accessibility compared with airports.

1.4 TAV Engineering Standards

1.4.1 The design for TAV is based on generic high speed rail technology with specific provision for a dedicated, fully segregated alignment to maximise running speed and ensure high operational performance in terms of reliability and punctuality, in accordance with the characteristics set out above.

1.4.2 It is not envisaged in the current feasibility studies that TAV will share any existing track or use joint running with existing Brazilian rail or metro services. The TAV alignment provides for dedicated tracks to the main station in each city with the alignment often located in tunnels in dense urban areas. A schematic layout of TAV is shown in Figure 1-2.

1.4.3 The TAV alignment has been developed based on international high speed line standards, more specifically:

- a maximum design speed of 350 km/h and 1,435 mm gauge with electrified track. **This should not be confused with the maximum operating speed which in this case is set at 300km/h (see section 2.4);**
- a maximum design gradient of 3.5% and 25 ton axle load[2];
- twin and single bore tunnels designed where applicable for 350km/h operation, and a maximum viaduct height of 70 metres for major bridges;
- stations with 'by-pass', or 'through' lines to maintain high speed running and platforms capable of accommodating 400m trains. 'Through' lines avoid the need for trains to slow for safety reasons which would be the case if passing through platforms;
- a signalling system capable of operating at 3 minute headways with in-cab signalling and cab-secure radio;
- TSI Infrastructure Standards (used for operational modelling and CAPEX definition purposes the standard Interoperability of the Trans-European National Standards Organisation, dated 19/03/2008);
- European standards were also used generically for CEN (European Centre for Standardisation), CENELEC (European Committee for Electrotechnical Standardisation, and ETSI (European Telecommunications Standards Institute; and
- UIC (Union Internationale Des Chemins de Fer) leaflets and ABNT (Associação Brasileira de Normas Técnicas) standards.

1.4.4 The precise engineering parameters are set out in the Terms of Reference for this study (Annex 2, Section 2-14).

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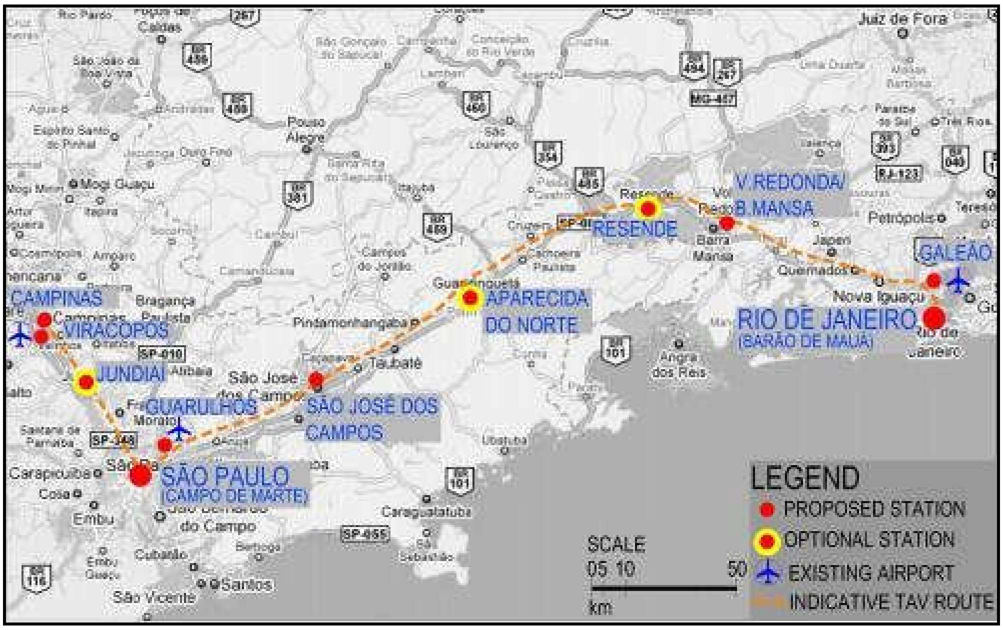
[2] Please note that HSR trains commonly have an axle weight of circa 17 tons. Recent Japanese high speed trains have an even lower axle load at 11 tons. However, during construction and maintenance periods freight trains would be used, which have a higher axle load, but lighter axle loads during actual operation will have an impact on track wear and maintenance. The axle load of 25 tons is specified in the Terms of Reference (Annex 2 - Section 2-14).

1.5 TAV Alignment and Stations

1.5.1 TAV will run between Campinas, São Paulo and Rio de Janeiro (see Figure 1-2). The TAV alignment developed also fulfils an aspiration to connect the airports of Viracopos, Guarulhos and Galeão with the major urban areas. The total estimated distance between Campinas and Rio de Janeiro is 511 km, while the distance between São Paulo and Rio de Janeiro is approximately 412 km. There are eight proposed/mandated stations in the base case and three further optional stations. Optional stations are shown in green in Figure 1-2.

1.5.2 Based on the TAV alignment developed, the non-stop journey time between the two cities is estimated at approximately 1 hour 33 minutes based on 300km/h operation. It is important to stress that TAV journey times will vary depending on the number of stations stops, with Regional long distance services between Rio de Janeiro to Campinas taking up to 2 hours 23 minutes. All journey times are approximate and are dependent on the final alignment, stopping patterns, and train performance including maximum speed, braking and acceleration characteristics. **The journey times shown in this report are therefore indicative and have been developed to assess the overall feasibility of the project**.

Figure 1-2: TAV Schematic



1.5.3 TAV will have a mix of new and refurbished stations and a new purpose built alignment. In Rio de Janeiro there are plans to refurbish and rebuild the abandoned station at Barão de Mauá (km 0[3]) which is close to the main bus station at Novo Rio. Provision has also been allowed for a light[4] maintenance facility and stabling sidings at Barão de Mauá. The next station is a new underground station to serve Rio de Janeiro's international airport at Galeão (km 15.2). From Galeão the line climbs through the mountainous region of Sierra das Araras which is the major engineering challenge, requiring numerous sections of tunnels and viaducts.

[3] All distances are from Barão de Mauá at Rio de Janeiro.

[4] The terms 'light' and 'heavy' maintenance are used as follows. 'Light' maintenance refers to cleaning, maintenance checks and watering of trains, while 'heavy' maintenance refers to major maintenance such as removal of bogies, wheel turning, major service checks and so on. Stabling sidings are required at all major terminal stations so that trains can be prepared for service.

1.5.4 A further station is planned at Volta Redonda/Barra Mansa (km 118.3), located within the state of Rio de Janeiro. Volta Redonda is an important industrial area with Latin America's largest steel mill. There is also provision for an optional station in the future at Resende[5], to the west of Volta Redonda/Barra Mansa.

1.5.5 Travelling westwards TAV then crosses the state border between São Paulo and Rio de Janeiro states. Provision has been made for a possible spur from the main alignment to serve a new optional station at Aparecida. Aparecida is an important pilgrim site which generates 9.5 million visitors per year (2008).

1.5.6 After Aparecida TAV then reaches the large industrial city of São José dos Campos (km 328.7). São José dos Campos is an important centre for high technology centred on aerospace and engineering, with a population of 1.4 million. This city is the proposed location of the rolling stock maintenance depot, as it has access to the main highway network, has a well developed regional airport, houses the Embraer assembly factory and has available land to accommodate high impact land use.

1.5.7 Westwards from São José dos Campos the next station is at São Paulo's international airport at Guarulhos (km 390.4), which will be built underground.

1.5.8 Upon reaching São Paulo, a preferred station site has been identified at Campo de Marte (Km 412.2), which is currently a federal airfield in the north of the city. In the Consortium's opinion, the selection of Campo de Marte provides an opportunity to build a major land mark station, but improvements will be needed to deal with the distribution of passengers within São Paulo, as the site is not served by the metro system.

1.5.9 Campo de Marte station will have a number of 'through' platforms to allow trains to run from São José dos Campos to São Paulo and then north westwards towards Campinas, without reversing.

São Paulo to Campinas

1.5.10 From São Paulo, the TAV alignment then turns north westwards towards Campinas. Further analysis was undertaken by the Consortium to examine the potential to reduce the maximum line speed between Campo de Marte and Campinas. Given concerns over the high overall construction costs, reducing the maximum line speed is a potential strategy to reduce the capital cost by allowing TAV to avoid natural obstacles rather than use tunnels or bridges to meet strict geometric criteria for 350km/h running. This is also sensible from a demand perspective because even at relatively modest speeds, TAV will enjoy considerable competitive advantage over existing bus and car modes because of traffic congestion in the corridor between Campinas and São Paulo. However, due to the topography between São Paulo and Campinas, which contains a series of small hills lying across the alignment, a significant speed reduction, potentially below 100km/h, would be required before any real cost savings could be achieved and for this reason no further analysis was undertaken. Reducing the maximum line speed of this section to Campinas would also impact on any future aspirations for TAV to serve stations beyond Campinas in future projects.

1.5.11 On the alignment there is provision for an optional parkway style station at Jundiaí, located between Anhanguera and Bandeirantes highways. The TAV alignment then proceeds northwards to include a further station at Viracopos airport (Km 487.6). Thus the TAV alignment fulfils an aspiration of the Government to connect the airports of Viracopos, Guarulhos and Galeão with the major urban areas. The final station is at Campinas (Km 510.7), the third largest city in the state of São Paulo after São Paulo and Guarulhos. This will also be a refurbished station including stabling sidings.

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[5] The alignment has been straightened to allow for a station at Resende.

1.6 Timetable Development

1.6.1 This section describes how the demand forecasts set out in Volume 1 are used to develop a timetable for TAV. The first task is to identify individual flows between stations and allocate these to service groups. In simple terms, the largest flow of passengers within each service group determines the number of trains required and their frequency.

1.6.2 Based on the demand forecasts developed in Volume 1, three main train service groups can be identified which reflect distinct markets for TAV. One of the strengths of the TAV project is that it is not dependent on a single market or revenue stream and the importance of commuting flows into São Paulo should not be under estimated as they account for more than 40% of revenues. The potential for TAV to serve three of region's major airports is also a further strength, as they generate considerable demand[6]. The grouping of TAV services also allows for the possibility of different types of train, which are customised to the markets they serve e.g. different seating configuration, door design, catering facilities, luggage space and so on.

1.6.3 The three proposed TAV service groups are as follows:

- **Express services** from São Paulo to Rio de Janeiro[7] operating non-stop; Express services will primarily compete against existing air services between the two cities;
- **Regional long distance services** operating between Campinas and Rio de Janeiro, with stops at Viracopos, São Paulo, Guarulhos International Airport, São José dos Campos, Volta Redonda/Barra Mansa, and Galeão International Airport. This service also performs an "airport" role by stopping at Viracopos, Guarulhos and Galeão airports and all major urban areas in the area of influence; and
- **Regional short distance services** operating between Campinas and São José dos Campos, with stops at São Paulo and Guarulhos International Airport. These services are primarily aimed at the commuting market between Campinas and São Paulo, and São José dos Campos and São Paulo. These services do not call at Viracopos Airport.

1.6.4 The terms 'Express', 'Regional short distance' and 'Regional long distance service' are adopted in this report to ensure consistency with the terms used in Volume 1: Demand and Revenue Forecasts. The demand forecasts presented in Volume 1 are developed as the 'Express sub-model' and 'regional sub-model', and are used as the basis for developing the train plan detailed in this report.

Rio de Janeiro - Campinas

1.6.5 Note that the flow between Campinas and Rio de Janeiro, while developed in the express sub-model (because of the need to consider air competition) in the demand report, is considered to be a regional long distance service in this volume. At this stage, a non-stop service between Campinas and Rio de Janeiro could not be justified because of the small market (See Table 1-1). One alternative is to extend the Express service to Campinas but this would increase the size of the estimated Express fleet and for this reason it was rejected. In any case Regional long distance services provide a direct connection between these stations without the need to change trains, and the time penalty for additional station stops is minimal.

1.6.6 As will be discussed later trains in all three TAV service groups will run at identical maximum speeds and will have similar acceleration and braking characteristics. While the internal layout of the Regional and Express trains could vary it is not recommended to operate trains with a large variation in performance due to the impact on capacity.

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[6] Most major international airports are served by a rail link, with the design contemplated here being similar to that recently opened to serve Charles de Gaulle Airport in Paris.
[7] Note in Volume 1 the flow between Rio de Janeiro and Campinas is included in the express sub-model. In the train planning work presented here this flow is allocated to the regional services.

1.6.7 It should be noted that the eventual operator may decide to brand Regional and Express services using market-oriented terms (such as 'Javelin' used for the new Channel Tunnel Rail Link high speed commuter service in the UK, or 'Eurostar' used for the high speed rail service between London, Paris and Brussels, or 'Thalys' for services between Paris and Brussels). We use the above nomenclature purely as descriptive terms for this study and to ensure consistency with the terms used in the demand forecasts.

Allocation of Demand Flows

1.6.8 The origin and destination pattern of these services between stations, for the forecasting start year 2014 and years 2024, 2034 and 2044 are illustrated in Table 1-1, Table 1-2, Table 1-3 and Table 1-4 below. The blue squares indicate express flows and green squares indicate regional short and long services.

1.6.9 Regional services have particularly significant traffic flows from São Paulo to São José dos Campos, and from São Paulo to Campinas. These discrete flows along the route indicate it will be more cost effective to terminate some of these regional trains part way along the route e.g. at São José dos Campos, rather than for all Regional stopping service trains to travel the entire length to Barão de Mauá; hence the decision to split regional services into short and long distance service groups to reflect these markets.

Table 1-1: Total Traffic Forecast by Origin & Destination Station (000 Trips): 2014

	Rio de Janeiro	Galeão	Volta Redonda/Barra Mansa	São José dos Campos	Guarulhos	São Paulo	Viracopos	Campinas	Totals
Rio de Janeiro		687.5	1,309.5	105.5	#	3,217.5	n/a	318.0	5,638.0
Galeão	687.5		52.0	n/a	#	#	n/a	n/a	739.5
Volta Redonda/Barra Mansa	1,309.5	52.0		127.0	n/a	92.0	n/a	20.0	1,600.5
São José dos Campos	106.5	n/a	127.0		80.0	4,276.5	n/a	652.5	5,241.5
Guarulhos	#	#	n/a	80.0		*	n/a	176.5	256.5
São Paulo	3,218.0	n/a	92.0	4,276.5	*		$	6,186.0	13,772.5
Viracopos	n/a	n/a	n/a	n/a	n/a	$		207.0	207.0
Campinas	318.0	n/a	20.0	652.5	176.5	6,186.0	207.0		7,560.0
Totals	**5,638.5**	**739.5**	**1,600.5**	**5,241.5**	**256.5**	**13,772.0**	**207.0**	**7,560.0**	**35,015.5**

n/a These flows were not estimated and are expected to be minimal

* The flow between São Paulo to Guarulhos is assumed to be carried by the Guarulhos Airport Express or similar project

This is a possible market for TAV, which is currently served by the airlines. Please see Volume 1 section 8.5 for more details.

$ Depending on the development of Viracopos, this could also be a significant future market for TAV

Table 1-2: Total Traffic Forecast by Origin & Destination Station (000 Trips): 2024

	Rio de Janeiro	Galeão	Volta Redonda/Barra Mansa	São José dos Campos	Guarulhos	São Paulo	Viracopos	Campinas	Totals
Rio de Janeiro		1,130.3	1,635.5	147.0	#	5,100.5	n/a	540.5	8,553.8
Galeão	1,130.3		85.3	n/a	#	#	n/a	n/a	1,215.7
Volta Redonda/Barra Mansa	1,635.5	85.3		168.5	n/a	116.5	n/a	27.5	2,033.3
São José dos Campos	147.0	n/a	168.5		131.9	5,745.0	n/a	1,001.5	7,193.9
Guarulhos	#	#	n/a	131.9		*	n/a	290.3	422.2
São Paulo	5,100.5	#	116.5	5,745.0	*		$	8,547.0	19,509.0
Viracopos	n/a	n/a	n/a	n/a	n/a	$		340.2	340.2
Campinas	540.5	n/a	27.5	1,001.5	290.3	8,547.0	340.2		10,747.0
Totals	**8,553.8**	**1,215.7**	**2,033.3**	**7,193.9**	**422.2**	**19,509.0**	**340.2**	**10,747.0**	**50,015.1**

n/a These flows were not estimated and are expected to be minimal

* The flow between São Paulo to Guarulhos is assumed to be carried by the Guarulhos Airport Express or similar project

This is a possible market for TAV, which is currently served by the airlines. Please see Volume 1 section 8.5 for more details.

$ Depending on the development of Viracopos, this could also be a significant future market for TAV

Table 1-3: Total Traffic Forecast by Origin & Destination Station (000 Trips): 2034

	Rio de Janeiro	Galeão	Volta Redonda/Barra Mansa	São José dos Campos	Guarulhos	São Paulo	Viracopos	Campinas	Totals
Rio de Janeiro		1,594.5	2,105.5	211.0	#	8,674.0	n/a	987.5	13,572.5
Galeão	1,594.5		120.4	n/a	#	#	n/a	n/a	1,714.8
Volta Redonda/Barra Mansa	2,105.5	120.4		228.5	n/a	154.0	n/a	39.5	2,647.9
São José dos Campos	211.0	n/a	228.5		186.0	8,141.0	n/a	1,555.0	10,321.5
Guarulhos	#	#	n/a	186.0		*	n/a	409.6	595.6
São Paulo	8,674.0	#	154.0	8,141.0	*		$	12,452.5	29,421.5
Viracopos	n/a	n/a	n/a	n/a	n/a	$		479.9	479.9
Campinas	987.5		39.5	1,555.0	409.6	12,452.5	479.9		15,924.0
Totals	**13,572.5**	**1,714.8**	**2,647.9**	**10,321.5**	**595.6**	**29,421.5**	**479.9**	**15,924.0**	**74,677.7**

n/a These flows were not estimated and are expected to be minimal

* The flow between São Paulo to Guarulhos is assumed to be carried by the Guarulhos Airport Express or similar project

This is a possible market for TAV, which is currently served by the airlines. Please see Volume 1 section 8.5 for more details.

$ Depending on the development of Viracopos, this could also be a significant future market for TAV

Table 1-4: Total Traffic Forecast by Origin & Destination Station (000 Trips): 2044

	Rio de Janeiro	Galeão	Volta Redonda/Barra Mansa	São José dos Campos	Guarulhos	São Paulo	Viracopos	Campinas	Totals
Rio de Janeiro		2,293.0	3,027.5	303.0	#	12,474.0	n/a	1,420.0	19,517.5
Galeão	2,293.0		173.1	n/a	#	#	n/a	n/a	2,466.1
Volta Redonda/Barra Mansa	3,027.5	173.1		328.5	n/a	221.5	n/a	56.5	3,807.1
São José dos Campos	303.0	n/a	328.5		267.5	11,707.5	n/a	2,236.5	14,843.0
Guarulhos	#	#	n/a	267.5		*	n/a	589.0	856.5
São Paulo	12,474.0	#	221.5	11,707.5	*		$	17,907.5	42,310.5
Viracopos	n/a	n/a	n/a	n/a	n/a	$		690.2	690.2
Campinas	1,420.0		56.5	2,236.5	589.0	17,907.5	690.2		22,899.6
Totals	**19,517.5**	**2,466.1**	**3,807.1**	**14,843.0**	**856.5**	**42,310.5**	**690.2**	**22,899.6**	**107,390.5**

n/a These flows were not estimated and are expected to be minimal

* The flow between São Paulo to Guarulhos is assumed to be carried by the Guarulhos Airport Express or similar project

This is a possible market for TAV, which is currently served by the airlines. Please see Volume 1 section 8.5 for more details.

$ Depending on the development of Viracopos, this could also be a significant future market for TAV

Peak Hour Demand

1.6.10 To plan the train service it is also necessary to consider the expected peaks in demand during the day, during the week and during the year. The parameters that were used to develop this were based on current observations of traffic movements along with future projections, namely:

- for the Express Service 35% of daily traffic is concentrated in the three hour morning peak (06.00 – 09.00 hours) and 35% in the three hour evening peak (17.00 – 20.00 hours);
- for the Regional services 25% of daily traffic is concentrated in the morning peak (06.00 – 09.00), 25% in the evening peak (17.00 – 20.00) and 20% at lunchtime (12.00 – 14.00);
- the weekly distribution of traffic is 16.3% each day from Monday – Friday, 7.7% on Saturday and 10.8% on Sunday; and
- the annual traffic totals were transformed into weekly totals by assuming 52 weeks a year.

1.6.11 Full details of the assumptions used here can be found in Volume 1 section 7.10. The geographical and time distribution of demand was fed through into the timetabling exercise to determine the required capacity of each train and the service frequency.

Developing the Timetable

1.6.12 Train timetables usually adopt a regular pattern of services such as hourly, half-hourly, every 20 minutes, every 15 minutes, every 10 minutes, every 5 minutes etc. to provide this capacity. A regular and consistent pattern tends to optimise capacity. Academic research has shown that passengers also find such a pattern easy to understand and this encourages patronage.

1.6.13 To plan the train service throughout the day it is usual to consider the period of highest demand which is the morning/evening peak service. An even interval off-peak timetable is then constructed between the morning and evening peaks. Finally, the train service is reduced until it closes late in the evening. It is also common practice for the first train of each day to run at reduced speed for safety reasons prior the commencement of high speed running.

1.6.14 In planning the service pattern it is necessary to integrate the various train service groups together in a way which ensures that the slower trains do not delay the faster ones. Passing loops at stations allow faster trains to overtake slower ones and these “overtaking” movements are built into the timetable; for example, slower trains are timetabled to depart from terminating stations “behind” the fast Express services (see Figure 2-3).

1.6.15 Many high speed railways have a daily maintenance period free of all train services for a few hours, normally during the early morning. This allows regular checks and small scale maintenance to be made to the infrastructure overnight. With the intensity of the train services operating at high speeds, it is very important to maintain the safety and integrity of the infrastructure.

1.6.16 At this feasibility study stage it is not sensible to specify a preferred rolling stock strategy, but to leave this open to bidders to encourage competition. For this reason, a generic high speed train was considered for the purposes of planning of both the express and regional services.

1.6.17 However, the two regional service groups have different market demands and it is recognised that the internal configuration of these may differ (e.g. the Campinas to São José dos Campos trains could have higher density seating of around 600 compared with the 458 of the Express service). However, there are considerable advantages from operating a standardised fleet in terms of operations, maintenance and procurement, and this will need to be considered by bidders.

2 Timetabling and Operations

2.1 Introduction

2.1.1 This feasibility study and the planning of the TAV system has been market led and the operational plan has been similarly configured to meet the projected demand for the railway. The aim of the timetable and operating plan are two-fold:

- to specify the service and resource requirements necessary to serve the projected demand; and
- to provide a basis for estimation of the operating costs of TAV.

2.1.2 This chapter covers the following areas:

- a summary of timetable planning and the process of train planning;
- a description of the main timetable planning tools used in the analysis;
- a description of the Railsys simulation of journey times;
- a summary of the specification of the route and station layouts;
- a description of the VoyagerPlan timetabling simulation;
- a consideration of future timetabling developments and issues; and
- an assessment of the rolling stock requirements.

2.1.3 It should be noted that the timetable, and operating costs which flow from it, have been developed to meet the demand forecasted in Volume 1 of the study. The timetable presented has been developed to show how TAV could be operated and the frequency and capacity of trains required commensurate with a feasibility study. However, most railways are based on an “asset sweating” philosophy whereby minor changes are made to optimise stopping patterns and journey times to find the best balance of operating costs versus revenue, given that a large proportion of costs are fixed. For example, the timetables presented here are based on standardised stopping patterns between peak and off peak services while in reality many off peak services may have additional stops to reflect the fact that users are less sensitive to journey times in these periods. Many of these changes can only be incorporated to the timetable once TAV is operating.

2.2 Timetable Planning

2.2.1 There has been considerable reliance on the outputs from other parts of the TAV study in producing the timetable and operating plans. Figure 2-1 shows the interdependencies between operations, train planning, and other work-streams.

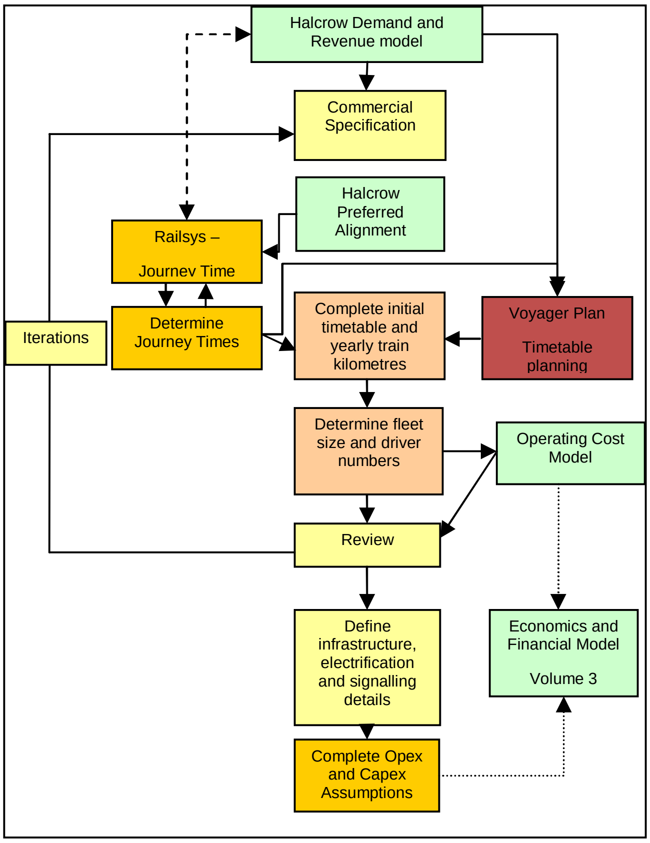
2.2.2 The key activities undertaken to produce the train plan are described below, beginning with close reference to the demand forecasts and ending with the generation of operating cost data. Section 2.3 provides a more detailed technical description of the train planning process and the software used.

- **Demand and Revenue Forecasts**. As discussed in Volume 1, detailed ridership forecasts have been developed based on initial journey times taken from previous studies. These were later refined based on the alignment proposed in this study, once this was completed.
- **TAV Alignment.** Based on Halcrow’s preferred alignment, important operational parameters were selected such as signalling headways, junction margins, platform

dwell and re-occupation times. These then allowed an initial timetable to be developed. Full details of the Alignment can be found in Volume 2.

- **Journey Times.** Using the Railsys simulation tool and the optimised Halcrow's preferred alignment, it was possible to simulate journey times between stations and timing points. Railsys uses the physical characteristics of the rolling stock (in this case high speed trains) to determine journey times. Different train schedules can be used (e.g. all stations or limited-stop) and different stock characteristics can be fed in to examine the impact on running times, if required. For this project, the characteristics of a generic high speed unit capable of the required speeds were considered. Once accurate journey times had been estimated, these were then fed back into the demand and revenue modelling, and the demand model was re-run.

Figure 2-1: Key Train Planning Process



- **Commercial Specification.** Annual demand forecasts have been developed into a commercial specification. The commercial specification reflects daily and seasonal variation in demand and defines the first and last trains, peak hour demand, number of trains, minimum acceptable frequencies, seating capacity and so on.
- **Train Planning.** Once a set of journey times was defined, these were then electronically loaded into VoyagerPlan. VoyagerPlan is a train planning system and is used to produce an initial outline timetable (see below).
- **Train Capacity:** Key to the success of TAV will be its ability to accommodate the forecasted numbers of passengers in comfort. No passengers are assumed to stand on express and regional short and long distance trains.
- **Initial Timetabling.** Whilst the express service is relatively straightforward, the train plan was complicated by the need to accommodate this alongside the regional high-

speed stopping service. The need to inter-weave some services from Campinas and the airport shuttle into the main timetable added further complications. A need also existed to ensure the timetable specifications met all the infrastructure constraints and provided adequate levels of service to meet demand.

- **Rolling Stock:** Once the timetable was defined and had been proved to be workable, a set of rolling stock diagrams were constructed. These define the services each unit will work each day starting with its move from overnight stabling location and the number of trains it then works before finishing at night. The rolling stock diagrams also determine which train formations need to be strengthened to accommodate the additional demand in peak hours. This exercise is vital for informing fleet size and the running costs of the network. The number of 'under maintenance' units needed to support the timetable was also determined by this exercise. Unit diagrams were then produced for a number of purposes including determining the number of drivers and guards/conductors required, which is then fed into the operational cost modelling. The size of the rolling stock fleet also determines other parameters such as depot maintenance facilities and rolling stock maintenance, which also inputs into the cost modelling.
- **Cross-checking: infrastructure, electrification and signalling.** A further key stage involved ensuring that infrastructure design remained consistent with the train plan. This involved such issues as station platform lengths, power supply capacity, signalling and depots.

2.3 Timetable Planning Tools

2.3.1 The RailSys and VoyagerPlan systems were used to determine train running times and develop the resulting timetable. These are sophisticated rail industry train planning systems used by operators around the world. This section describes in detail how the train plan was developed using these systems.

RailSys

2.3.2 Railsys is used to estimate running times based on gradients, curvature, traction characteristics and so on. Railsys is used to remove the 'guesswork' from all stages of rail service planning. It is useful to civil engineers to allow accurate evaluation of the impact of new infrastructure on a route (such as eased speed limits) and it is used to assist signal engineers in the assessment of new or revised signalling schemes.

2.3.3 The infrastructure model of the TAV alignment was built in Railsys version 6. This is the UK standard rail simulation system tool, which is also used by consultants and rail operators throughout the world.

2.3.4 The Rolling Stock characteristics for a high speed train were imported into the model from the demonstration network of Railsys, which is based on actual data supplied by the manufacturers from high speed rail systems around the world. The TAV running time simulation was then run for the generic high speed train on the preferred route, to find the minimum running times between stations.

2.3.5 Trains are entered with different stations stops in accordance with the three defined service groups to allow a full range of stopping and passing running times between all stations. For example, stopping at only the end points of the route, stopping at all stations, and then at alternative stops. Both the minimum technical running times (flat-out full speed running according to the maximum line speed and gradients), and suggested timetabling running times (which includes a 6% allowance for recoverability), have been calculated in this way.

2.3.6 These calculated times were then used to construct the timetable during the train planning process described below.

VoyagerPlan

2.3.7 VoyagerPlan is a timetable and scheduling system used to develop timetable scenarios and undertake timetable and train diagramming (resources planning, e.g. train crew, and their associated costs) studies for a range of clients. It is the tool of choice for most UK Train Operators and Government authorities, but also used by operators around the world.

2.3.8 To support the generation of operating plans reference was made to the route geography, station locations and other interval markers which define the running lines and running times for each stock type. Running time information was derived from the RailSys modelling of the route.

TAV Train Specification

2.3.9 It was decided to use a generic train specification rather than one particular manufacturer's unit. This train specification was established from a combination of known and tested high speed train characteristics held within the RailSys modelling tool (as supplied by the manufacturers). These data were then used to set the parameters for the TAV RailSys model to calculate running times based on the TAV alignment, as set out in Volume 2.

2.3.10 To this end, a train or unit type was selected that offered both tested running characteristics and the relevant line speed required for TAV. Different variants of high speed rail technology will have slightly different performance characteristics. As several manufacturers currently offer high speed trains operating commercially at 300 km/h, this was used as the maximum operating speed for the timetable simulations. Please see Part 2 - Technology of this volume for more details on train performance.

2.3.11 It is understood that a number of manufacturers are currently marketing trains with a maximum speed of 350km/h or higher. The precise decision on the maximum speed should be left to bidders who will have to decide between proven technologies, i.e. 300 km/h versus the technology and performance risks of running at higher commercially unproven speeds. It should be stressed that the alignment has been designed for a maximum line speed of 350km/h, with restrictions only due to geometry or safety constraints (see section 2.4.5).

2.3.12 A key characteristic of HSR is the ability to meet punctuality and reliability targets and these targets should form part of the performance regime between the concessionaire and the Government (see Volume 3 for further details). In the demand study (Volume 1), TAV is only assumed to suffer 5 minutes of delay on average compared to air travel, which has 30 minutes of delay. The maximum line speed of 350km/h allows some scope for time recovery on late-running or delayed services and thus supports the study's train performance assumptions, if 300km/h running is assumed.

2.3.13 Table 2-1 shows the technical specifications of the generic stock used. It is important to note that the Consortium does not advocate any particular type of train or technology.

Table 2-1: High Speed Train Characteristics

Characteristic	
Train length	200 metres typically 8 cars
Maximum Axle Load	17 metric tons (Note: TAV is specified to 25 metric tons to allow for construction and maintenance trains as per the Terms of Reference – Annex 2, Section 2-14 c)
Tare Weight	436 tons
Maximum Commercial/Operating Speed	300km/h
Maximum Power at wheel	8,000 kW
Number of Seats	Express service train - 458 with two classes Regional service trains - We have assumed 600 seat

Characteristic	
	trains on regional services between Campinas and São Jose dos Campos in a single class.
Train Interior	Trains will have catering services which may include a buffet car, WC, wheelchair access and luggage space. The precise interior design will be left to bidders but details of typical fleet composition are given in Part II of this Volume.

2.3.14 Typical HS trains have an axle weight of 17 metric tons compared to 25 metric tons used in the alignment work (See Volume 2). A higher axle weight of 25 metric tons is required because maintenance and construction trains are heavier than passenger trains and hence it is necessary to allow for their operation. Maintenance is expected to take place during "white periods", as it is described later in this report.

2.3.15 The split between economy and executive classes is not defined at this stage but executive travel accounts for approximately 23% of TAV demand between Rio de Janeiro and São Paulo. The precise configuration and layout of TAV trains should be a decision for bidders. Rail fares, set out in Volume 1, assume a peak economy fare of R$200 and an off-peak economy fare of R$150 (including all taxes and charges). All fares are assumed to be constant in real terms. Please refer to Volume 1 for further details on fares.

2.4 Railsys Journey Time Simulation

2.4.1 Route parameters from the TAV alignment, as specified and output by QuantM, were input into the Railsys model. These parameters included distances between stations, gradients, curvature and speed limits. To simulate the proposed route it was necessary to determine timing points, which allowed comparison of journey times for different options e.g. stopping against non-stop operations.

2.4.2 The second important input is the train specification, as set out in Table 2-1, and examples of typical high speed trains are given in Part II of this volume. Train performance in terms of acceleration and braking, as well as maximum speed, are important in the journey time simulation. **The maximum operating speed for TAV is assumed to be 300km/h because the majority of existing high speed trains run at this speed (please see details given in Volume 4: Part 2- Technology).**

2.4.3 Railsys makes an important distinction between maximum line or track speed and actual operating speed, as follows

- **Maximum Line or Track Speed**. This refers to the maximum line speed or design speed of the line as used in the alignment optimisation work set out in Volume 2, section 3.5.6. Among the geometric parameters specified are the minimum horizontal (track) radii and maximum gradients allowable for 350km/h running. If the minimum track radius is exceeded i.e. tighter curves are required then the maximum line speed must be reduced and a speed restriction imposed; and
- **Maximum Operating Speed**: This is related to the technical characteristics of the train as set out Table 2-1 and the way in which the trains are operated. It is ultimately limited by the maximum line or line speed. While the maximum line speed may be 300km/h this does not mean that the train is capable of reaching or maintaining this speed on all sections. For example, in the Sierra das Araras maximum gradients and curvatures have been used which impact on train performance and are modelled in Railsys. The maximum operating speed is assumed to be 300km/h.

2.4.4 A third concept is the commercial or average speed which is estimated by simply the total journey time divided by the length of the line. Average speeds will therefore vary depending on the number of station stops and the timetable assumptions.

Alignment Speed Restrictions

2.4.5 As noted above the alignment optimisation work, as outlined in Volume 2 of this study, is based on a maximum line speed of 350km/h, provided the geometric criteria are met. All intermediate stations are based on four-track alignment which includes two by-pass lines in addition to two platforms, which avoids the need for any speed restrictions.

2.4.6 However, some speed restrictions (i.e. a reduction below 350km/h), are sometimes needed because some of the geometric criteria cannot be met. As described below, there are basically two main factors that drive the reduction in speed along the alignment:

- **Restrictions imposed by constraints in the alignment**

  In order to physically achieve the required alignment between stations, taking into account physical constraints imposed by the geography, topography, geology and so on, the geometric criteria have been relaxed. The adoption of more restricted values of curvature radii and gradients results in a reduction of the maximum speed that can be applied in these sections.

  In the case of urban areas, this does not impact significantly on the overall journey time because trains will either be accelerating or braking as they approach/depart terminal stations. For example, TAV trains departing from Barão de Mauá towards Galeão Airport will be accelerating and will not reach their maximum speed for a number of kilometres; the reverse will obviously apply as TAV trains approach Barão de Mauá. Similar considerations apply to Campo de Marte and Campinas. As a result of slower speeds in urban areas, the cross sectional area of the tunnels can be reduced from the design advocated for 350km/h running, which reduces the cost of tunnelling. This has been considered in the development of the capital costs as set out in Volume 5; and

- **Restrictions imposed by safety.**

  There is a considerable aerodynamic effect from running trains at high speed through tunnels, known as the ‘piston effect’. The tunnel cross sections as set out in Volume 2 are based on those developed for the HS line between Madrid and Barcelona (which is capable of attaining 350km/h running). However, this speed is not yet proven in operation and therefore for the TAV simulation a maximum speed in tunnels of 300km/h is assumed. So while the tunnels meet the geometric criteria for 350km/h running this is not yet proven in service. All tunnels outside main urban areas are assumed to have a maximum speed of 300km/h. Tunnels on CTRL in the UK currently operate at these speeds.

2.4.7 A summary of speeds by track section are shown in Table 2-2.

Table 2-2: Location of Major Tunnels and Speed Restrictions

Section	Start	End	Maximum Line Speed (s) km/h
Barão de Mauá - Galeão	**0,000**	**15,166**	Speeds between 60 km/h (approach Barão de Mauá) and 160 km/h
Galeão - Barra Mansa/ Volta Redonda	**15,166**	**118,302**	
	18,580	23,550	230 km/h: the Horizontal alignment is fit for 350km/h but is restricted to 230 km/h due to short vertical curve elements necessary for the change in elevation from tunnel beneath the Canal do Fundão to viaduct over the Supervia rail line (line between Duque de Caxias and Saracuruna) and crossings of nearby roads in the north of Duque de Caxias.
	81,610	82,650	300 km/h: Tunnel, Horizontal alignment fit for 350km/h
	83,490	90,670	300 km/h: Tunnel, Horizontal alignment fit for 350km/h
	99,660	100,950	300 km/h: Tunnel, Horizontal alignment fit for 350km/h
Barra Mansa/Volta Redonda - São José dos Campos	**118,302**	**328,663**	
	322,340	324,080	300 km/h: Tunnel (SJ dos Campos), Horizontal alignmnet fit for 350km/h
São José dos Campos - Guarulhos	**328,663**	**390,433**	
	383,620	390,000	230 km/h: Twin bore tunnels
Guarulhos - Campo de Marte	**390,433**	**412,244**	230 km/h: Twin bore tunnels
Campo de Marte - Viracopos	**412,244**	**487,594**	
	412,200	426,000	230 km/h: Twin bore tunnels
	429,600	430,890	230 km/h: Twin bore tunnels
Viracopos - Campinas	**487,594**	**510,760**	Currently 160km/h, will be partially raised to 230 km/h if achievable

Train service patterns and times

2.4.8 Having input details of the alignment, the type of train and point-to-point timings, the train service pattern and timings could be developed to best match the forecast demand profile. The approach was further informed through workshops, demand profiling to determine how the maximum revenues will be achieved, sensitivity analysis involving the various assumptions inherent in the timetabling systems and professional knowledge of other high speed rail systems.

2.4.9 The resulting train plan optimised timings, service reliability and commercial attractiveness. It includes the three distinct but separate service operations as discussed in Section 1.6.3, shown below:

- **Express services** from São Paulo to Rio de Janeiro**;**
- **Regional long distance services** operating between Campinas and Rio de Janeiro, with stops at Viracoposo, São Paulo, Guarulhos International Airport, São José dos Campos, Volta Redonda/Barra Mansa, and Galeao International Airport. This service also performs an "airport" role by stopping at Viracopos, Guarulhos and Galeão airports and all major urban areas in the area of influence; and
- **Regional short distance services** operating between Campinas and São José dos Campos with stops at São Paulo and Guarulhos International Airport. This service does not stop at Viracopos Airport.

2.4.10 The stopping patterns by station are shown in Figure 2-2 for the peak hour in 2014 and Table 2-3. As shown in Table 2-3 the busiest station will be Campo de Marte with 9 trains per hour (tph).

Table 2-3: TAV Frequency by Station

Station	Express	Regional Long Distance	Regional Short Distance	Total
Barão de Mauá (Rio de Janeiro)	3 tph	2 tph	-	5 tph
Galeão Airport (Rio de Janeiro)	-	2 tph	-	2 tph
Volta Redonda/Barra Mansa	-	2 tph	-	2 tph
São José dos Campos	-	2 tph	4 tph	6 tph
Guarulhos Airport (São Paulo)	-	2 tph	4 tph	6 tph
Campo de Marte (São Paulo)	3 tph	2 tph	4 tph	9 tph
Viracopos Airport	-	2 tph	-	2 tph
Campinas	-	2 tph	4 tph	6 tph

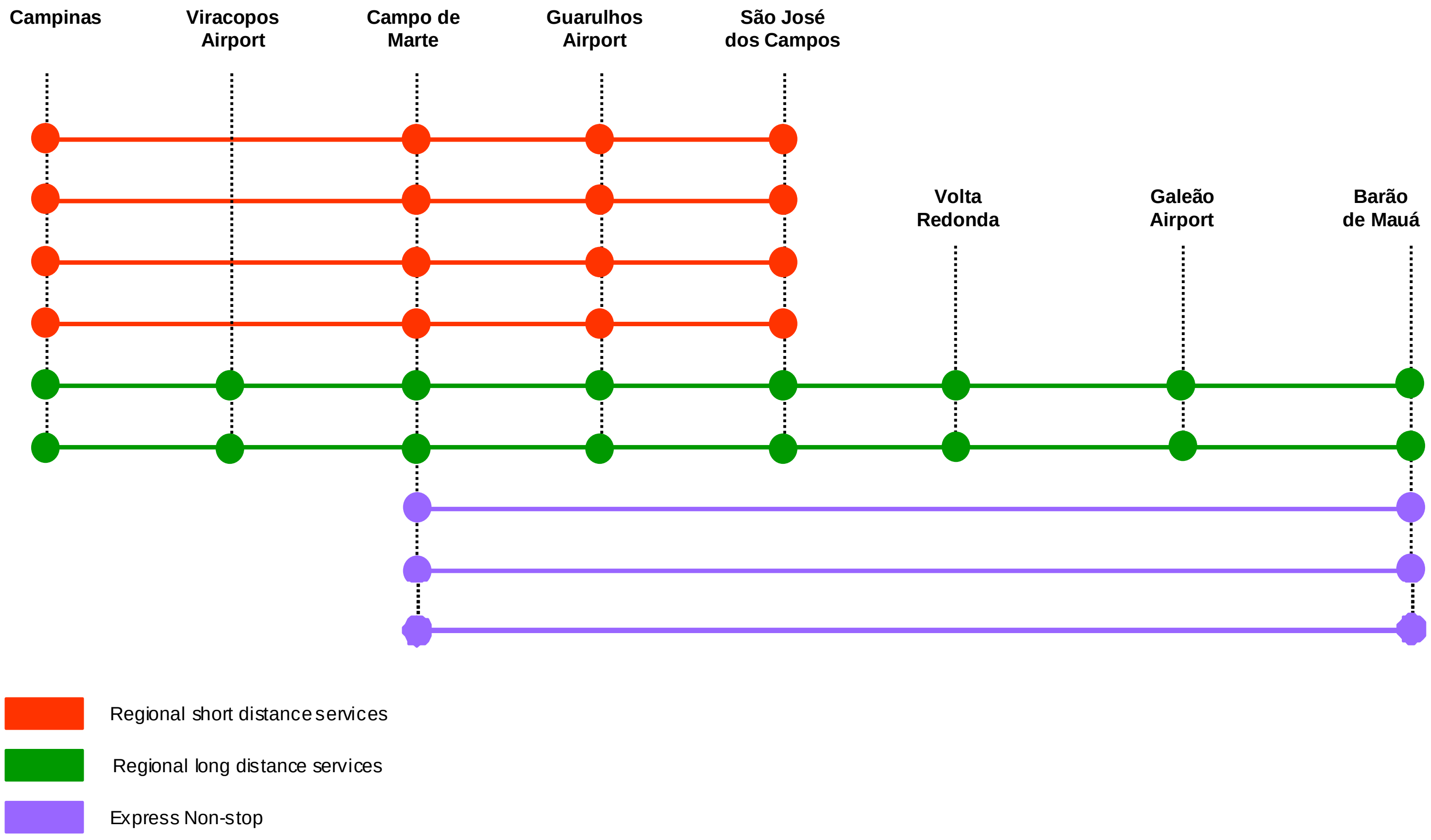


Figure 2-2: 2014 Peak Hour Service Standard Pattern

2.4.11 Using the RailSys modelling software package, the known route characteristics as set out in Table 2.2 and the alignment imported from QuantM, the journey times for Regional and Express trains were derived. Table 2.4, Table 2.5 and Table 2.6 show the journey times of each train service pattern (rounding up of each time to the nearest half minute). Note that it does not follow that in all cases journey times towards Barão de Mauá are the same as journey times in the reverse direction (See Table 2.4 and Table 2.5 for example) because TAV trains brake and accelerate at different rates, and gradients and track curvatures have a different affect on train performance depending on the direction of travel.

2.4.12 As shown in Table 2.4 based on a maximum operating speed of 300km/h, Express services will take 1 hour 33 minutes eastbound and a minute longer westbound, a journey time very attractive to passengers. As can been see from tables below it is possible for average speeds to vary by direction over the same section. This is plausible because the alignment gradient profile is directional which affects train performance during acceleration and braking phases. Speeds are also influenced by the location of stations and their relatively position. This is a result of the relatively short distances between stations which do not allow the train to reach cruising speed before it has to begin braking.

Table 2-4: Express Train Service Journey Times at 300km/h

From	To	Station Stops	Journey Times (Hours:Min:Sec) Average Speed
Campo de Marte	Barão de Mauá	none	1:33:00 280 km/h
Barão de Mauá	Campo de Marte	none	1:33:30 264 km/h

Table 2-5: Regional Long Distance Services at 300km/h

From	To	Station Stops	Journey Times (Hours:Min:Sec) Average Speed
Campinas	Barão de Mauá	Viracopos, Campo de Marte, Guarulhos Airport, São Jose dos Campos, Volta Redonda/Barra Mansa, Galeão Airport	2:33:30 200 km/h
Barão de Mauá	Campinas	Galeão Airport, Volta Redonda/Barra Mansa, São Jose dos Campos Guarulhos Airport, Campo de Marte, Viracopos	2:26:30 209 km/h

Table 2-6: Regional Short Distance Trains at 300km/h

From	To	Station Stops	Journey Times (Hours:Min:Sec) Average Speed
Campinas	São Jose dos Campos	Campo de Marte, Guarulhos Airport	1:04:00 172.5 km/h
São Jose dos Campos	Campinas	Guarulhos Airport, Campo de Marte	57:30 192 km/h

2.4.13 Table 2.7 shows the sectional running times along various sections of the route. Four different train times are provided - start to pass, pass to pass, pass to stop, and start to stop.

'Start to Pass' means that the train 'starts' from first station but does not stop at the next. 'Pass to Pass' assumes the train passes through both stations without stopping, and hence these are the fastest section times. 'Pass to Stop' assumes the train passes the first station but stops at the next. 'Start to Stop' assumes the train starts from the first station and stops at the next. Hence, Table 2.7 reflects the impact of including station stops. All station stops are assumed to be two minutes in accordance with international operating standards.

2.4.14 On the basis of Table 2.7 the running time between Barão de Mauá and Campo de Marte can be estimated as follows:

- Barão de Mauá to Galeão – start to pass – 07:30 minutes;
- Galeão - Volta Redonda/Barra Mansa – pass to pass – 22:00 minutes;
- Volta Redonda/Barra Mansa - São Jose dos Campos – pass to pass – 42:00 minutes;
- São Jose dos Campos to Guarulhos Airport – pass to pass – 14:00 minutes;
- Guarulhos Airport to Campo de Marte – pass to stop – 08:00 minutes;
- gives a total time of 93.5 minutes, or 1 hour 33.5 minutes, as shown in Table 2.4

2.4.15 The timings of Express services reflect the maximum speed along the route sections i.e. 'Pass to Pass'. The section from São José dos Campos to Barra Mansa/Volta Redonda has no speed restrictions and express trains achieve a 299 km/h average, very close to their maximum operating speed. On some sections there are small variations in eastbound and westbound speeds which principally relate to the local topography e.g. the Serra das Araras, between Barra Mansa/Volta Redonda and Rio de Janeiro.

Table 2-7: Train Service Running Times (300 km/h)

From	To	Distance	Running Times (to half minute)				Average Speed (kph)	
		Km	Start to Pass	Pass to Pass	Pass to Stop	Start to Stop	Express	Regional
Campinas	Viracopos Airport	22.4	00:10:00			00:10:30	n/a	127.91
Viracopos Airport	Campo de Marte	76.0			00:19:30	00:22:00	n/a	207.40
Campo de Marte	Guarulhos Airport	21.6	00:08:00		00:09:00	00:09:00	144.00	144.00
Guarulhos Airport	São José dos Campos	63.0	00:15:00	00:14:00		00:16:00	252.00	236.25
São José dos Campos	Barra Mansa/Volta Redonda	209.6		00:42:00		00:45:00	299.43	279.47
Barra Mansa/Volta Redonda	Galeão	102.9		00:21:30		00:24:30	287.16	252.00
Galeão	Barão de Mauá	15.0			00:07:30	00:08:00	120.00	112.50
From	To	Distance	Running Times (to half minute)				Average Speed (kph)	
		Km	Start to Pass	Pass to Pass	Pass to Stop	Start to Stop	Express	Regional
Barão de Mauá	Galeão	15.0	00:07:30			00:08:00	120.00	112.50
Galeão	Barra Mansa/Volta Redonda	102.9		00:22:00		00:24:00	280.64	257.25
Barra Mansa/Volta Redonda	São José dos Campos	209.6		00:42:00		00:45:00	299.43	279.47
São José dos Campos	Guarulhos Airport	63.0		00:14:00	00:14:30	00:16:30	260.69	229.09
Guarulhos Airport	Campo de Marte	21.6			00:08:00	00:09:00	144.00	144.00
Campo de Marte	Viracopos Airport	76.0	00:20:00			00:21:30	n/a	212.09
Viracopos Airport	Campinas	22.4			00:10:00	00:10:30	n/a	128.00
n/a – the average speeds for express and regional trains are the same for this section as all trains stop at Campo de Marte and Guarulhos								

2.5 TAV Stations and Depots

2.5.1 The route map shown in Figure 2-13 below demonstrates the proposed/mandated stations which were modelled and the approximate distances between timing points[8]. There are also three optional stations being considered for which future provision is being made in the alignment development work only. The optional stations are at Resendé, Aparecida and Jundiai. Station layout plans for the key stations along the route were produced along with generic station layout for the intermediate stations. A summary of the key characteristics and location of these stations is shown in Table 2.8.

Table 2-8: Station Characteristics and Locations

Station	Description	Station Location (Km)
Barão de Mauá (Rio de Janeiro)	Terminus (3 island platforms with 6 platform faces)	0.0
Galeão Airport (Rio de Janeiro)	2 platforms 2 through lines	15.1
Volta Redonda/Barra Mansa	2 platforms 2 through lines	118.0
São José dos Campos	5 platforms one of which is a terminal platform 2 through lines	327.5
Guarulhos Airport (São Paulo)	2 platforms 2 through lines	390.5
Campo de Marte (São Paulo)	6 platforms.	412.2
Viracopos Airport	2 platforms 2 through lines	488.2
Campinas	Terminus (4 platforms)	511.1

2.5.2 Turn back locations to turn around train service groups are provided at Campo de Marte, Barão de Mauá, Campinas and at São José dos Campos. These turn back locations require extra platforms and nearby depots or sidings for the stabling of trains to ensure trains are ready to enter service as required. The following is a description of the recommended station layouts.

Barão de Mauá

2.5.3 Barão de Mauá is the terminating station in Rio de Janeiro. The proposed layout for this station is three island platforms with six platform faces. This would be the minimum requirement to meet the forecast demand to use the system. Due to increased demand in future years and subsequent need for double length trains in the peak hours the platform and station approach will require the following characteristics:

- Platform Length: 500m;
- Station approach: 400m; and
- Width per double platform: 12m.

2.5.4 There will also be a need for a 'shunt neck' running between the two arrival lines and multiple crossovers to allow entrance to the marshalling and stabling sidings that will be positioned alongside the station. These are all shown in Figure 2-3: and Figure 2-4.

[8] The optional stations of Resende, Aparecida and Jundiai are not considered in this analysis

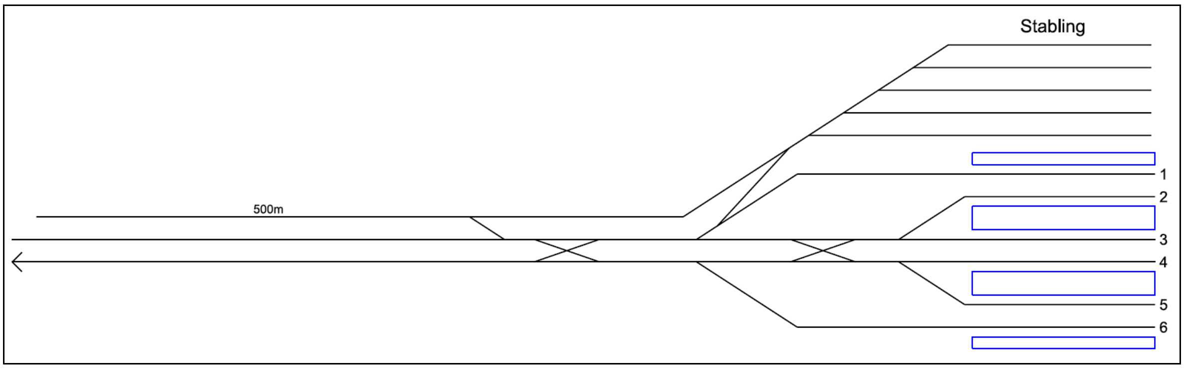


Figure 2-3: Barão De Mauá Station lay-out

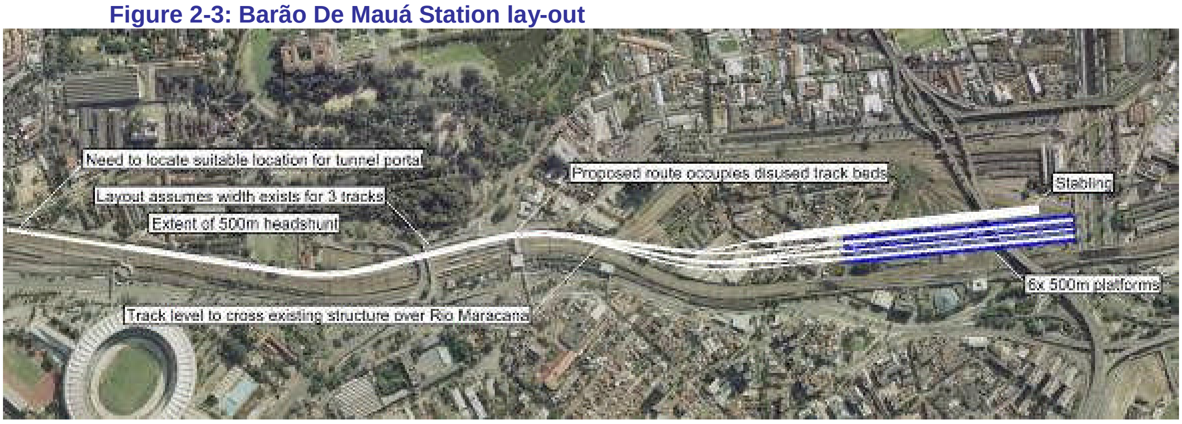


Figure 2-4: Barão De Mauá Station approach

Galeão International Airport

2.5.5 This station will be operated with two platforms on the outside of the loops, as shown in Figure 2-5 and Figure 2-6. This arrangement allows for the safe operation of Express train services away from passengers standing on the platforms waiting for the stopping trains. It also has operational benefits by allowing express and stopping trains to overtake. All platforms will be at least 420 metres long to allow for double length (400 metres) train services to cater for future growth.

Figure 2-5: Galeão International Airport Station showing access to terminals

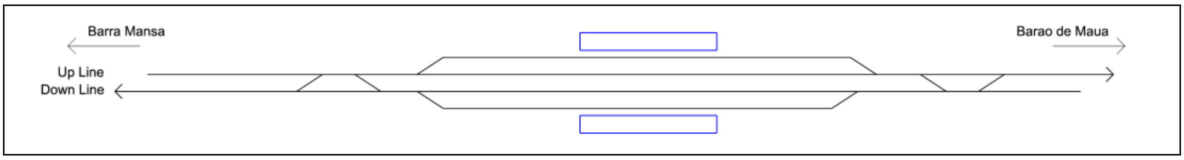


Figure 2-6: Galeão International Airport Station layout

Barra Mansa/Volta Redonda

2.5.6 This station is another 'through' station and the recommended layout is the same as Galeão Airport. This is shown in Figure 2-7.

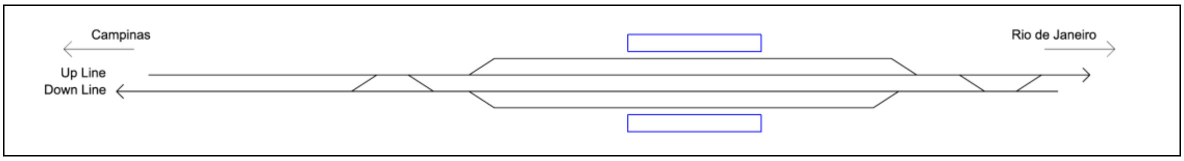


Figure 2-7: Barra Mansa/Volta Redonda Station layout

São José Dos Campos

2.5.7 Although this is an intermediate station and not a terminus, it has been determined through the train planning process outlined earlier, and the demand forecasting work, that São José dos Campos offers the best location to turn around Regional short distance trains back to São Paulo, as shown in .

2.5.8 It is recommended therefore that the layout should allow a full mixture of service patterns to use the station simultaneously. As can be seen by the layout below, five platform faces have been recommended, with one terminal platform on the outside. These outside platforms would be reached using a grade separated or 'flying' junction over the main line to allow the continuity of other services.

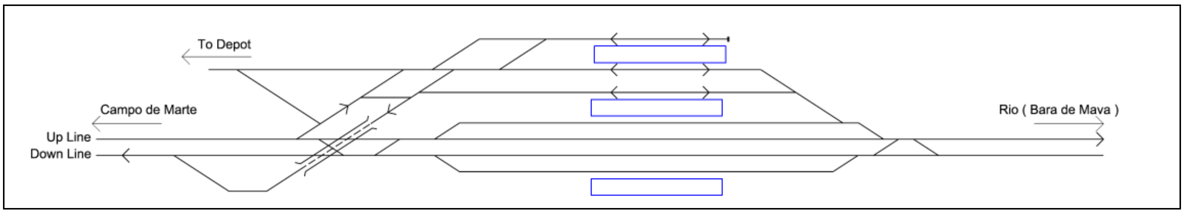


Figure 2-8: São José dos Campos Station layout

Guarulhos International Airport

2.5.9 Guarulhos airport is another 'through' station. The recommended layout separates stopping trains from through trains using loop lines to allow safe operation and to maximise operational efficiency and capacity, as shown in .

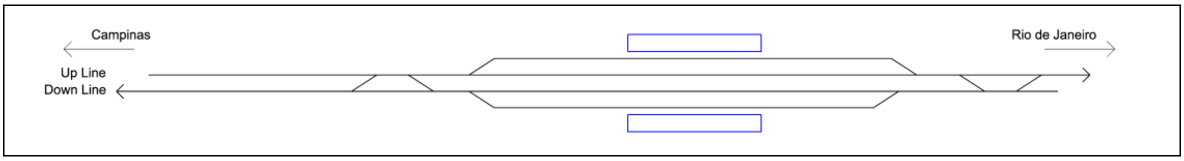


Figure 2-9: Guarulhos International Airport Station layout

Campo de Marte

2.5.10 This is the terminating station at São Paulo for Express trains, but is configured to operate as a through station. It is recommended that the platform arrangement is three island platforms with six platform faces. There are also a number of crossovers and shunt lines which allow any service to enter any platform from any direction. Bi-directional signalling is required to allow for maximum operational flexibility. The linking of all the platforms and lines leads to train performance benefits as well as allowing improved platform working in what may prove to be limited available space.

2.5.11 There is also the need for stabling facilities at this location and it is proposed that these go near or around the Campo de Marte site. These facilities will be accessed by means of a shunt neck, a stretch of line which connects the main running lines with the stabling facility. shows the proposed layout at Campo de Marte.

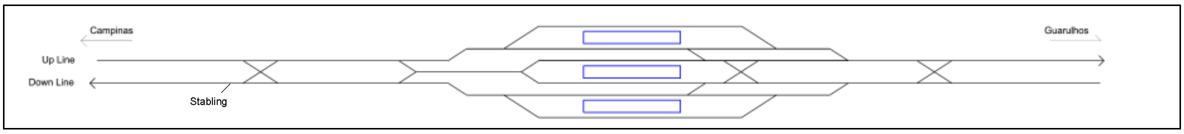


Figure 2-10: Campo de Marte Station lay-out

Viracopos Airport

2.5.12 This station is another 'through' station with two platforms and the recommended layout is the same as Galeão Airport, as shown in .

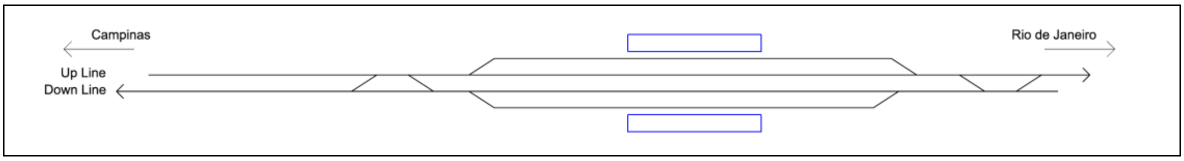


Figure 2-11: Viracopos Airport Station layout

Campinas

2.5.13 Campinas will be a terminating station and will have stabling facilities, as shown in . As a result, there will be a requirement for a shunt neck connecting the main running lines with the stabling sidings. It is recommended that this station have two island platforms with four platform faces. This allows for future expansion of the Express services from Rio de Janeiro via São Paulo if required, as well as allowing for the high volumes of demand that will use the services.

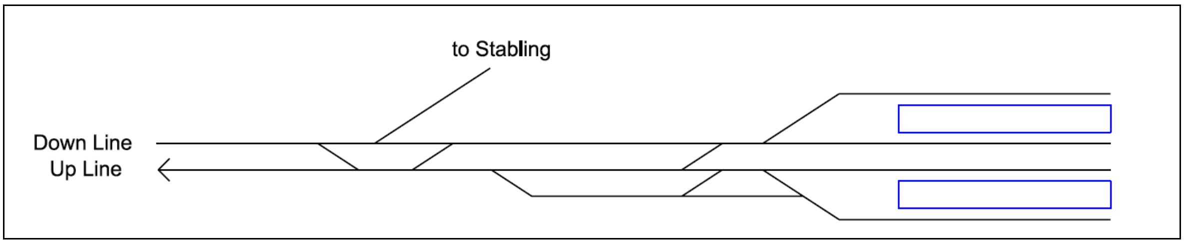


Figure 2-12: Campinas Station layout

Optional Stations

2.5.14 The alignment has passive provision for an optional station at Resende. This would also be a 'through' station and the recommended layout is the same as Barra Mansa/Volta Redonda.

2.5.15 The alignment has passive provision for an optional station at Aparecida to meet the demand for the pilgrimage periods to the Basilica de Aparecida. However, due to the position of the alignment a short connecting line would be required. The connecting line would be accessed from the mainline via a junction and would be a single line and single platform. Trains would then reverse to rejoin the main line.

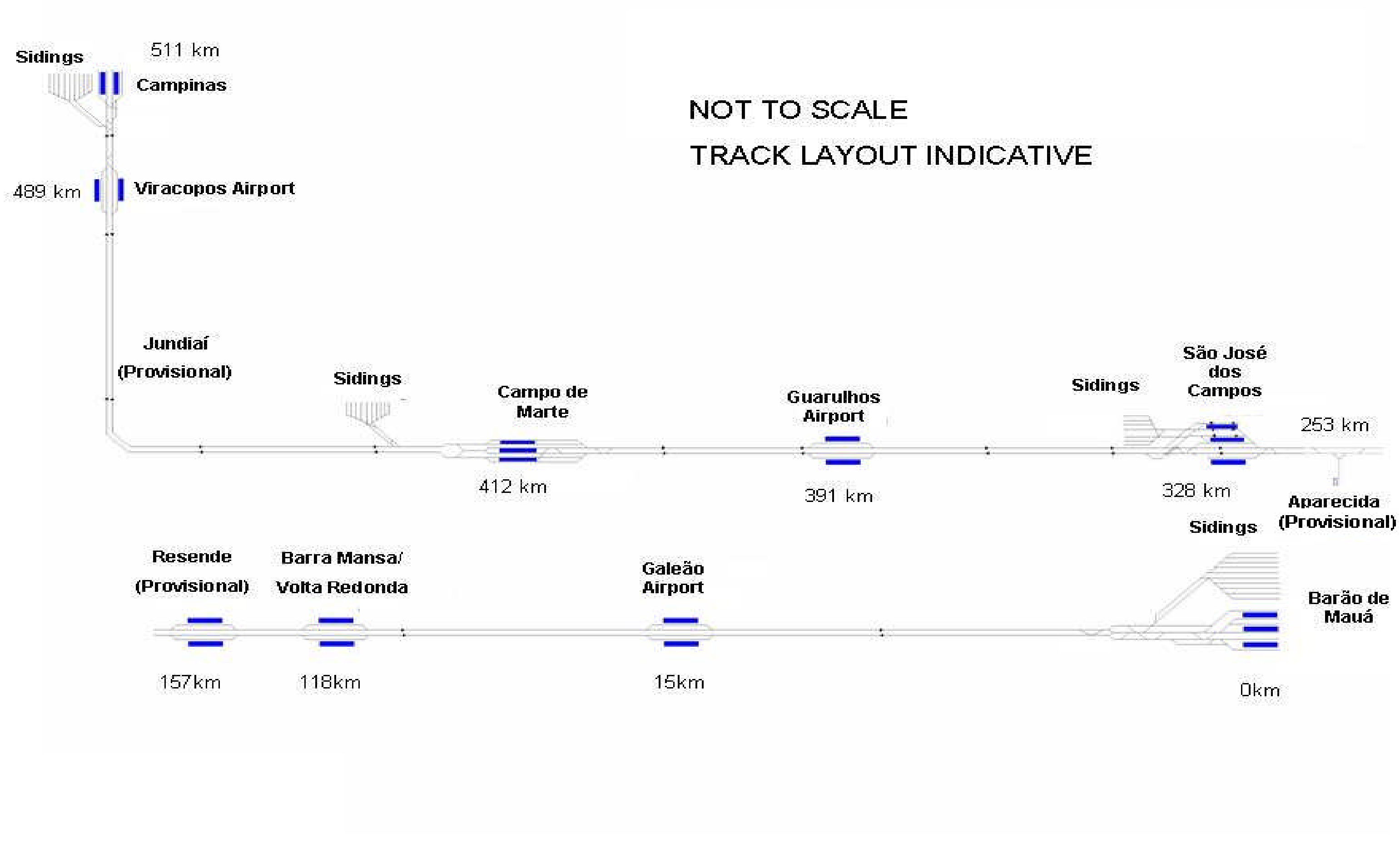
2.5.16 The alignment has passive provision for an optional station at Jundiai. This would also be a 'through' station and the recommended layout is the same as Barra Mansa/Volta Redonda.

Switches and Crossovers

2.5.17 Crossovers are a vital performance benefit, as a means of dealing with incidents (e.g.: failed trains), maintenance, and to assist with high traffic volumes. From our experience of systems worldwide the best operated railway systems with the best performance are those which have crossovers at regular intervals. These provide continuity of service and access to key locations. It is recommended that crossovers should be provided as follows:

- before and after every intermediate station;
- in tunnels if they have single bore;
- before and after long tunnels;
- before major terminals at each end of the route;
- beginning and end of Campo do Marte;
- all depot and engineering sidings;
- any branch lines (e.g. plan for potential future station at Aparecida); and
- wherever the space between existing crossovers is greater than 50 km.

Figure 2-13: Proposed Route Layout



Train Maintenance Depots

2.5.18 The heavy maintenance depot will be based in São Paulo state as the large proportion of the fleet will operate there. It is recommended that the depot be located at São José dos Campos because of the technology skill base in the area, its strategic location along the route and the availability of land.

2.5.19 Due to the large fleet there will also be a requirement for stabling facilities. Logically these should be close to the terminating stations to reduce trains running empty and using resources needlessly. It is therefore suggested that the following locations are used for stabling/light maintenance: Barão de Mauá, Campo de Marte, São José dos Campos and Campinas.

Track maintenance/Engineering

2.5.20 There will be a need for track maintenance sidings to stable track maintenance machinery and equipment, including track inspection vehicles. It is proposed that there are three main locations with additional equipment for major refurbishments and secondary locations that could both act as emergency repair locations and light maintenance. The following locations were considered to offer the best locations for track maintenance/engineering sidings.

- main maintenance depots: Jundiaí, Volta Redonda and São José dos Campos; and
- secondary maintenance depots: Rio de Janeiro.

2.5.21 Each siding at the main locations would be made up of sidings ranging from 500 – 1,500 metres, with approximately 10 sidings at each end of the route. These would be placed at the same locations described above for stabling. The layouts of the sidings should start with lines of 500m increasing in length to 1,500 metres sidings, with ten siding lines at each end of the route. There will also be a need for a maintenance shunter/haulage system.

2.6 VoyagerPlan Timetabling

2.6.1 As described above, the demand forecasts were turned into a commercial specification for timetable planning. To develop this specification it was necessary to match the demand to the proposed train service patterns, including details such as the peaks in demand and train operating hours.

Operating hours

2.6.2 The demand report shows that approximately 70% of the current passenger traffic between the two cities of Rio de Janeiro and São Paulo are business travellers. These will therefore be the principal market segment in the peak period and the demand profile uses this as the base for capacity planning.

2.6.3 From the demand model it has been determined that the first trains leaving from each terminal station should be at 06:00 and the last trains should leave at 23:00. As well as allowing sufficient services to meet the forecast demand for all routes this also allows for an effective daily maintenance window for route works.

Determining Capacity for Peak Operation

2.6.4 From the demand profile it is possible to determine the peak hours. These are as follows:

- morning peak: 06:00 – 09:00;
- evening peak: 17:00 – 20:00; and
- lunch time peak : 12:00 – 14:00 (regional trains only).

2.6.5 From this the number of services that are required to operate during the peak periods to meet the demand and the number of vehicles required per train can be determined, e.g. based on three trains per hour between 06:00 and 09:00 hrs delivers 1,374 seats, compared to an estimated demand of 1,176 for one hour or an estimated occupation of 86%. A similar analysis for Regional services, based on 600 seats per train, gives an average occupation of

78%. Note that, as stated earlier, the precise configuration of the two types of trains requires further detailed analysis outside the scope of this present study.

2.6.6 As demand grows for Express and Regional services over time, and as set out in Table 1-1, Table 1-2 and Table 1-3 average occupancy increases in line with demand growth. Hence for Express service trains will be close to 100% capacity by 2017/2018, the point at which additional capacity is required. It has therefore been assumed that a doubling of capacity is required by then. This can be achieved by the procurement of additional carriages to lengthen the train formation i.e. from 200 metres to 400 metres; this is shown by the green cells in Table 2-9.

2.6.7 As high speed trains tend to comprise integrated units with a fixed number of vehicles each, it has been assumed that capacity will be expanded by doubling train size from one to two units. In reality the operator would seek to optimise the capacity of the existing fleet in an attempt to defer the purchase of additional trains; techniques include, for example, running additional peak only trains through more sophisticated diagramming of trains to increase their availability, or price discrimination i.e. increasing peak fares to encourage travel in off-peak periods where there is spare capacity. By 2030 capacity is reached again (as highlighted in red in Table 2-9) and a potential solution to increase capacity is shown in , which requires an increase in frequency but no further expansion of the rolling stock fleet. Capacity is again reached in 2038 beyond which further track capacity is required beyond that of the proposed TAV layout.

2.6.8 As shown in Table 2-9, Regional services start with an initial average occupancy of 78%, which is lower than the occupancy expected for Express services because of the higher train capacity at 600 seats and higher frequency.

2.6.9 The basic service patterns for both Express and Regional services are shown in . Based on estimated demand growth Regional services will be at capacity around 2021/2022, at which point capacity is doubled in the peak hour without any increase in frequency, as shown in green in Table 2-9. Trains are extended from 200 metres to 400 metres, and as a result average occupancy drops to 51%. 100% occupancy is not achieved by 2040, so no further rolling stock is required, but a potential solution to increase capacity beyond this is shown in .

Table 2-9: Average Occupation by Type of Service

Service Type	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Express Trains	86%	90%	94%	98%	51%	54%	56%	59%	62%	65%	68%
Regional services	78%	81%	84%	87%	90%	93%	96%	99%	51%	52%	54%

Service Type	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Express Trains	73%	77%	82%	87%	92%	96%	76%	79%	83%	87%
Regional services	57%	59%	61%	64%	66%	68%	71%	73%	76%	78%

Service Type	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
Express Trains	90%	94%	98%	More Track Capacity Required						
Regional services	81%	85%	88%	92%	95%	98%	91%	94%	97%	100%

2.6.10 The basic off-peak service pattern is planned to start at 05:00 although a few very early longer distance services start at 04:00. This will allow reasonable arrival times, such as a first service from Campinas starting at 04:00 and arriving at Rio de Janeiro at 06:19. These off-peak services may also assist with the high demand during peak hours. Pricing strategies could be used to entice peak hour travellers onto these off-peak services.

2.6.11 No solutions were developed beyond 2034, as this would likely require additional track, platforms and rolling stock plus upgrades to signalling systems, electrification, depots and so on.

Table 2-10: Basic Service Pattern by Type of Service and Year

Service Type	Period	Seats per train	Peak hours		Off Peak hours		Trains per day	Average journey time
			Trains per hour per direction	Service interval	Trains per hour per direction	Service interval		
Express	2014 – 2017	458	3	20 min	1.5	40 min	85	1 hr 31 min
	2018 - 2030	458 x 2	3	20 min	1.5	40 min	85	1 hr 31 min
	2031 - 2037	458 x 2	4	15 min	2	30 min	102	1 hr 31 min
Regional short distance	2014 - 2021	600	2	10 min	2	20 min	111	1 hr
	2022 - 2040	600 x 2	2	10 min	2	20 min	131	1hr
	2040 – 2044	600 x 2	5	8 – 9 min	2	20 min	187	1hr
Regional long distance	2014 - 2021	600	2	30 min	1	60 min	53	2 hr 25 min
	2022 - 2040	600 x 2	2	30 min	1	60 min	53	2 hr 25 min
	2040 - 2044	600 x 2	2	30 min	1	60 min	53	2 hr 25 min

Modelling the Train Service Pattern

2.6.12 The geography set in VoyagerPlan comprises of the "tiplocs" (timing point locations) which are stations and junctions, and "network links" which join locations together as tracks. The point-to-point times from RailSys (see above) are then entered into VoyagerPlan.

2.6.13 A train is set up by entering the start location of the train's origin and then linking it to the locations it stops at or passes through. VoyagerPlan picks up the running times to determine the train's time at each station. A train type can then be replicated to produce the whole pattern of trains, based on the service intervals described above.

2.6.14 Timetable planning has a number of factors which must fit together to make a plan work:

- train headways: when moving a train a headway space must be maintained in front of it to avoid it being delayed by red signals;
- platforming: trains must have platform space allocated to stop at or turn back in a station;
- junction or platform ends: when entering or leaving a platform, a train must not conflict with any other train coming from any direction; and
- unit diagramming: trainsets must be available to form each train service at the start of each journey.

2.6.15 When all the train service patterns have been set up they are then displayed graphically, as shown in Figure 2-13, which shows a distance/time graph with each line representing the passage of a train; blue sections show where trains have stopped stations. It was assumed the headway interval will be three minutes which is the minimum time allowed between trains by the signalling system[9] for reasons of safety. Trains are arranged on the graph so that they are at least three minutes from the train in front and behind. Planning trains closer than this would result in trains being delayed by red signals, or equivalent for in-cab signalling.

2.6.16 As the Regional long distance services travel slower than the express service, some of those trains must wait for six minutes at either Barra Mansa/Volta Redonda or at São José dos Campos, to allow the express trains to overtake on the mainlines. Figure 2-13 illustrates this happening at São José dos Campos. As well as being able to run along the lines between the locations, the trains must have space in a platform at stations where they will stop. Trains which are turning back to form a service in the other direction require platform space for a longer time. Figure 2-14 illustrates an example of a platform occupancy graph feature of VoyagerPlan.

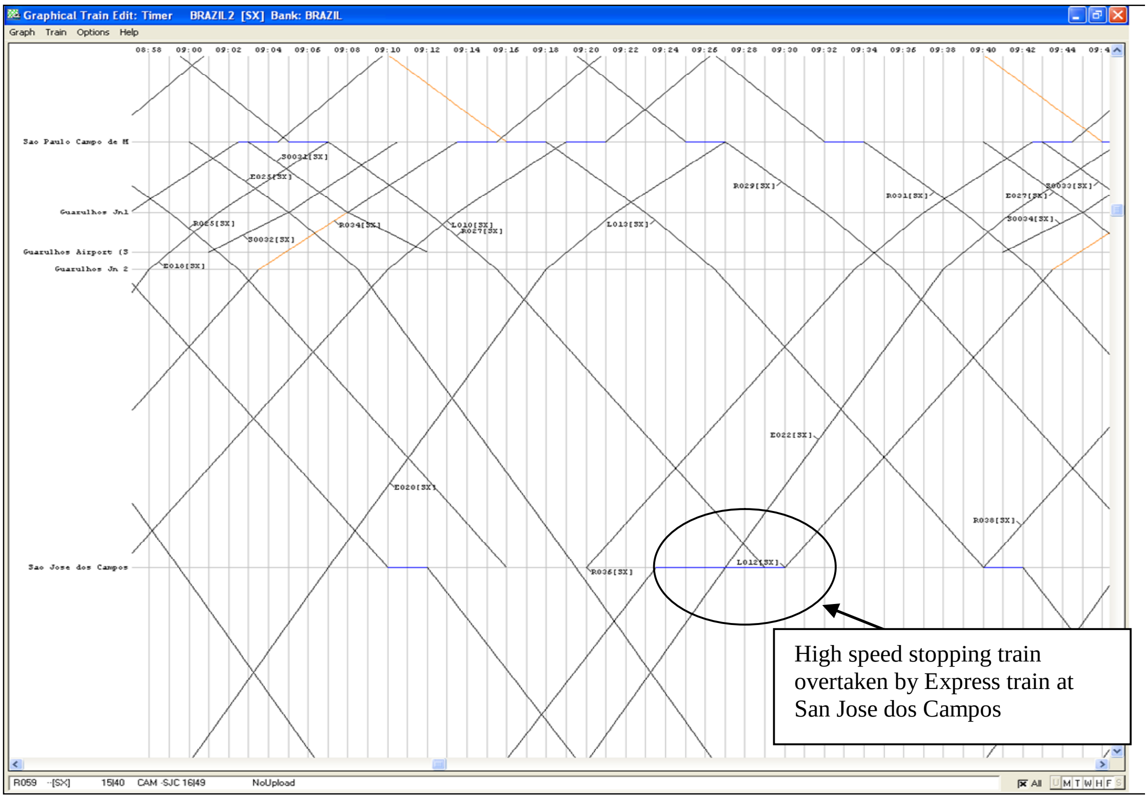


Figure 2-14: VoyagerPlan Train Service Output

[9] A signalling system compatible with ERTMS Level 2 is assumed with in-cab signalling capability. Other comparable systems are available from US and Japanese manufacturers.

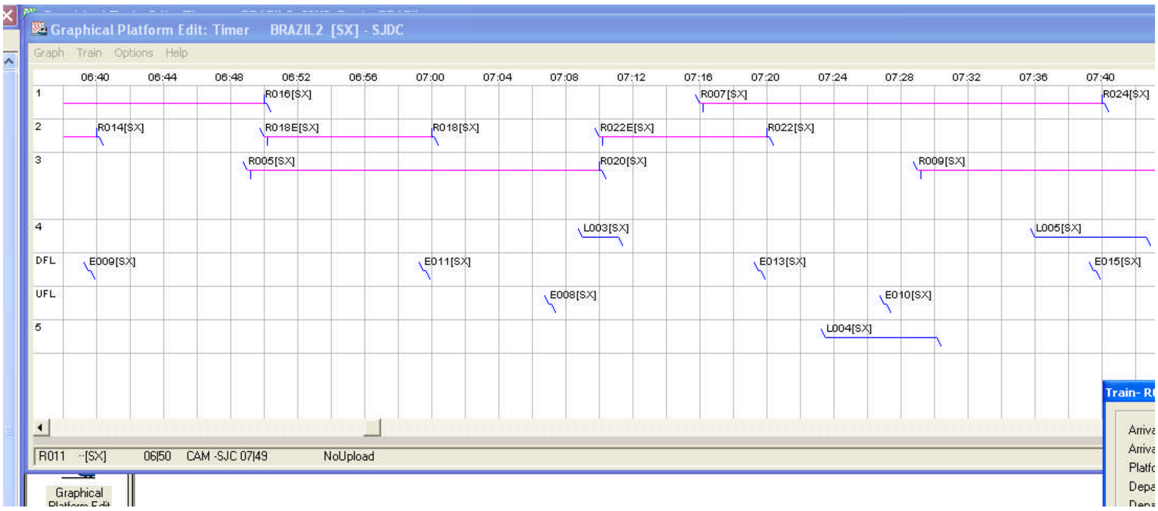


Figure 2-15: VoyagerPlan Platform Occupation

2.6.17 This platform graph of São José dos Campos (Figure 2-14) at the beginning of the morning peak shows:

- Express trains run through the Up[10] and Down fast lines. These are shown with short blue slanted lines;
- Regional long distance services between Campinas to and from Rio de Janeiro stop in Platforms 4 and 5. These are shown with the longer blue lines indicating their dwell time e.g. train L003 stops for the minimum of two minutes to allow passengers on and off, but trains L005 and L004 dwell for six minutes to allow express trains to over take them on the mainlines; and
- Regional short distance services between Campinas and São José dos Campos turn back here to form a return working. This requires a longer dwell time (shown in pink). Empty trains will also come from São José dos Campos depot to form some of the earlier morning peak services (shown by the shorter pink lines).

2.6.18 The number and pattern of trains passing through, stopping and turning back at a station will influence the design and layout of the station, and determine the number of platforms required. The platform graph also influences the diagramming of train sets as they usually turn around there.

2.7 Turnaround Times & Unit Numbers

2.7.1 One of the important factors used to plan a train service is the time interval between a train service arriving at a station and its departure. This is more important for terminating stations where the majority of the passengers are likely to board/alight the services, and where train servicing will also take place, such as inside cleaning, rubbish collection, replenishing catering stocks and replenishing water tanks for toilet operation and so on. Some operators also have on-board rubbish collection to reduce servicing time at terminal stations.

2.7.2 Taking into account the high volume of passengers which will use TAV and the limited space available, the assumptions on minimum turn-back times, based on best practice from around the world, are as follows in Table 2-11.

[10] 'Up' denotes trains towards Rio de Janeiro and 'Down' denotes trains towards São Paulo/Campinas

Table 2-11: Train Service Turnaround Times

Service type	Station	2014 - 2017	2018 - 2030	2030 – 2037
Express	Campo de Marte	30 minutes	30 minutes	15 minutes
Express	Barão de Mauá	30 minutes	30 minutes	30 minutes
Service type	**Station**	**2014 - 2021**	**2022 - 2040**	**2040 - 2044**
Regional long distance service	Barão de Mauá	25 minutes	25 minutes	25 minutes
Regional long/short distance service	Campinas	20 minutes	20 minutes	15 minutes
Regional short distance service	São José dos Campos	20 minutes	20 minutes	15 minutes

2.7.3 Turnaround times include incoming passengers leaving the train, any maintenance checks and restocking required, and for outgoing passengers to board. There is normally an allowance to catch up for late running due to delays. In this way a longer turn back will allow a more robust service but potentially increase the number of platforms required. Longer distance services usually have longer turn back times as there is more chance of delay on route. There is more likely to be a requirement for restocking and cleaning of the train, as passengers have spent longer on the train. The TAV service is relatively short for an express train (around 1 hour 33 minutes) and a full cleaning, replenishment, watering of the trains will not be necessary at each single trip.

2.7.4 For operational planning, turnaround times are assumed to be the same for 2014 until 2030 for Express trains and 2040 for Regional trains with the only difference being the doubling of train capacity but no change in the core frequencies. In reality a more detailed solution to manage passenger growth could be developed, for example, a phased introduction of capacity over time rather than in a single step, or re-diagramming existing sets to release capacity at peak periods. Although outside the scope of this study, further work is recommended to develop a more detailed operational plan.

2.7.5 Lower turnaround values for 2030 are necessary due to higher frequencies and restrictions on the number of platforms, especially at Campo de Marte. The longer turnaround time at Rio de Janeiro has been maintained to ensure robustness in the timetable, and allow for any out of course running. It is anticipated that by 2030 the necessary station activities can be completed faster as staff/establishment will be more experienced, or due to more efficient processes. The alternative is that additional platforms will need to be built at Campo de Marte to allow this level of service. The 2030 turnaround times are therefore considered to be achievable, but are only one possible solution to increasing capacity to cater for further demand growth. Further detailed validation work is required to ensure that the turnaround times given in Table 2-11 are achievable.

2.7.6 Based on the turn backs planned at the terminating stations, it is possible to build up the unit diagrams. Depending on the number of platforms at each station some units can stay in the platform overnight to form the first services of the following day. The other units will need to start from the depots/sidings next to the terminating stations.

2.7.7 Return services will be based on the minimum turn back values and the space available in the platform. This determines the maximum turn back time. A train set's diagram follows the same train unit along each of the services it forms. As there is no permissive working where more than one train is in the same platform, trains turning back generally arrive and leave a station in the same order. More train services are required during the peaks, so off-peak some train units will return to the depots until they are again needed in the next peak.

2.7.8 The rolling stock requirements by service group are summarised Table 2-12 below.

Table 2-12: Number of Train Sets by year

Train Type	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Express	14	14	14	14	28	28	28	28	28	28	28
Regional	25	25	25	25	25	25	25	25	50	50	50
Spares	3	3	3	3	6	6	6	6	6	6	6
Total	42	42	42	42	59	59	59	59	84	84	84

Train Type	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Express	28	28	28	28	28	28	28	28	28	28	28
Regional	50	50	50	50	50	50	50	50	50	50	50
Spares	6	6	6	6	6	6	6	6	6	6	6
Total	84	84	84	84	84	84	84	84	84	84	84

Train Type	2036	2037	2038	2039	2040	2041	2042	2043	2044
Express	28	28	28	28	28	28	28	28	28
Regional	50	50	50	50	50	50	50	50	50
Spares	6	6	6	6	6	6	6	6	6
Total	84	84	84	84	84	84	84	84	84

2.7.9 As discussed, it is proposed that system capacity can be increased to cater for future demand by doubling the train lengths, hence the doubling in express unit diagrams from 39 to 59 in 2018 and from 25 to 50 for regional services in 2022. The fleet would additionally include three spare sets (increased to six in 2018) to cover for those undergoing maintenance and two high speed locomotives which would be used for the recovery of failed trains and hauling line inspection vehicles.

2.7.10 The estimated fleet requirement for 2014 compares favourably with that currently operating on the Korean high speed network. TAV is estimated to require 45 sets to carry around 40 million passengers per year in total (all services). The Korean system currently operates 46 sets and transports around 38 million passengers per year. Whilst the two networks differ in several respects (for example, Korean trains travel over significant lengths of conventional track not yet upgraded for high speed whilst the TAV system will accommodate large short-distance commuter flows) this comparison indicates broad compatibility and therefore supports the proposals for TAV.

3 TAV Operating Costs

3.1 Introduction

3.1.1 The previous section sets out the development of timetables for TAV. This section takes the outputs of the timetabling work and develops operating costs for input into the financial and economic model as set out in Volume 3.

3.1.2 This section covers the following areas:

- a discussion about the drivers of operating costs;
- an overview of the sources of operating costs;
- derivation of infrastructure maintenance costs;
- derivation of train and customer service costs; and
- derivation of rolling stock maintenance costs.

3.1.3 TAV operating costs are split into two main categories: asset maintenance and train operations, as shown in Table 3-1 below

Table 3-1: Cost Drivers for Operating Cost Model

Category	Sub-category	Key Driver
Infrastructure Maintenance	Track maintenance	Length of (tunnelled and surface) route
	Station maintenance	Number of stations
Train and customer service	Station staff	Number of stations, number of annual journeys
	Train personnel (Drivers & Conductors)	Number of train diagrams
	Management and overheads	Number of stations and train personnel
Rolling Stock Maintenance	Train maintenance	Train kilometres
	Train energy	Train kilometres

3.1.4 It is reasonable to assume that TAV will benefit from the latest construction techniques and railway technology. For example, advances in in-cab signalling systems require very little trackside maintenance compared to traditional line side signals. Indeed, evidence from other railway administrations has shown that maintenance costs on newly constructed lines are lower than conventional networks. Development of new technologies such as high output ballast cleaners and train monitoring machines can also improve maintenance efficiency over time compared to conventional methods.

3.1.5 Bidders will be expected to bring the latest construction techniques to bear on the TAV project, and in accordance with the philosophy of PPP/DBFO construct assets with a view to whole life cost rather than an initial low investment cost which subsequently is expensive to maintain. A good example of this is the use of slab track which is much more expensive to install (1.5 to 2.0 times more expensive than traditional sleeper and ballast) but maintenance costs are much lower (0.18 to 0.33 times lower). Using these assumptions on a whole life cost basis slab track is 12% lower than traditional sleeper and ballast in total cost terms[11]. Most countries have, however, opted for conventional ballasted track rather than implementing slab track. The final choice on slab track is a decision for bidders.

3.1.6 Maintenance regimes and equipment redundancy have a big impact on maintenance costs which are hard to control across railway administrations. Maintenance on the Shinkansen network is based on a philosophy of extensive preventative maintenance, examinations, and monitoring to a much higher standard than used in Europe.

3.1.7 Axle loading also has a big impact on track wear and it has been assumed here no high speed freight trains will be operated on the TAV alignment. Moreover, the design gradient for TAV at 3.5% would be unsuitable for freight operation.

3.1.8 Worldwide, railway administrations use different accountancy standards for maintenance costs and this makes comparisons between administrations hard to achieve on a like-for-like basis. In Europe it is a legal requirement (91/440) to split costs between infrastructure and operations, and this is reflected in the organisational structure of railway administrations within the European Union i.e. vertical separation.

3.1.9 The methodology used in this study is based on benchmarking of operating costs compared to other railway administrations. Benchmarking of operating costs is difficult, for the reasons stated above, and care is required to ensure transferability to TAV. It is, however, reasonable to assume that TAV will be maintained to international standards, and in any case this would be a requirement of the concession agreement. Hence, international norms with regard to the replacement of track, S&C, ballast cleaning and so on are assumed to apply to TAV, as is rail maintenance technology such as on-track machines: rail grinders, tampers, ballast cleaners and so on.

3.2 Basis of Operating Costs

3.2.1 The operating costs presented are on a “per track kilometre”, or “per unit” basis and are averages taken from Halcrow’s in-house whole life cost databases which contain extensive international experience. It should be noted that Halcrow was involved in a major technical review of the UK’s Network Rail maintenance and renewal costs for the Office of the Rail Regulator (ORR) in 2008/2009, during which the long trends for maintenance costs were examined. The review considered the costs of maintenance and renewals for the UK network as part of Network Rail’s periodic review in 2008/2009, and drew heavily on international experience to determine the potential for efficiency savings.

3.2.2 In those cases where the adoption of international operating costs might not reflect the local costs, i.e. the cost of electricity, values given were based on rates supplied by PROMPT ENGENHARIA LTDA. (“PROMPT”). Whenever this was the case, this has been highlighted in the sections below. Full details of PROMPT ENGENHARIA LTDA’s work are given in Appendix B.

3.2.3 The difficulty of estimating reliable operating costs should not be under estimated as railways are long-life assets and true maintenance costs may only emerge after many years of operation when renewals and refurbishment need to be considered. Some operating costs are fixed, such as signalling and safety management systems and depend on technical and safety standards rather than traffic intensity.

3.2.4 Adjustments have been made for the fact that TAV will be a new railway, and will not use or share any existing conventional railway infrastructure, and that infrastructure costs are expected to be lower in the initial years of service, particularly for structures and tunnels. However, the scope for significantly lower track maintenance costs in Brazil, exploiting cheaper labour rates, is more limited because much of the work is mechanised e.g. tamping/ballast cleaning, and the equipment and tools will have to be imported. Plus the decision to adopt a 1,435mm track gauge will mean that any existing maintenance

[11] WS Atkins (2002) High Speed Line Study Milestone 8 Cost Model Report prepared for the SRA

equipment already in use in Brazil on domestic freight lines will be of very limited use, as they run on different track gauge.

3.2.5 For rolling stock, maintenance costs are better understood and more recent rolling stock builds have wrapped maintenance costs into capital costs under “power by the hour” arrangements. Under this model, widely used in the UK, manufacturers assume responsibility for maintenance, refurbishment and train overhauls. Typically, contracts with manufacturers are structured around the number of units required per day to operate the core service with penalties for failures in service. These types of contracts are also used in aviation for major components such as engines. This is discussed in more detail below.

3.2.6 All prices are in 2008/09 values and where other estimates have been used, these have been inflated appropriately. Table 3-2 shows the exchange rates used for converting costs into R$.

Table 3-2: Exchange Rates 2009

Currency	Rate
Exchange rate GBP (£) to Brazilian R$	3.46
Exchange rate Euro (€) to Brazilian R$	2.90
Exchange rate US Dollar (US$) to Brazilian R$	2.55

3.3 Permanent Way

3.3.1 Track maintenance is the most expensive operating costs because of the high standard of maintenance required to allow for high speed running. Based on Halcrow in-house sources and international bench marked an estimated rate of GBP £22.8K per track km was used for 1,104 km including an allowance for sidings and maintenance depots.

3.3.2 Typical track maintenance tasks include:

- track inspection patrols;
- ultrasonic rail flaw detection;
- rail grinding;
- replacement of rail fastenings; and
- maintenance of ballast and formation including plain line tamping.

3.3.3 Electrification has been estimated on a per structure basis (GBP £282 per structure) which includes an allowance for the following:

- overhead line equipment structures (20 per kilometre) e.g. electrification masts;
- autotransformers feeder stations;
- autotransformers stations; and
- other electrification equipment.

3.3.4 The term ‘structure’ used in Table 3-3 refers to an electrification mast or poles which are used to suspend contact wire and earth return cables above the track. Various electrification systems are available on the market and these are set out in Part II of this volume.

3.3.5 On the basis of advice received from international experts in signalling and telecommunications (S&T), ISV, annual maintenance costs for S&T are assumed to be 5% of capital costs. Table 3-3 lists the maintenance items considered:

Table 3-3: Permanent Way Maintenance Costs

	Unit Rate	Quantity	Cost (R$ per year)
Track Maintenance	£22.8k per track km	1,104 km	R$ 87.1m
Electrification	£282 per structure	29,781 structures	R$ 29.1m
Signalling & Telecommunications	5% of Capex Cost	R$630.8m	R$ 31.5m
Total Permanent Way			R$ 147.7m
Average costs per track Km			R$133,848 per track km

3.3.6 The average cost per track km is R$ 133,848 per Km or € 46,154 per track Km. A recent research paper examined empirical costs of construction and maintenance of high speed rail lines based on data supplied by the UIC[12]. The results of the research are shown in Table 3-4. Prices have been inflated from 2002 prices to 2009 based on 3.5% p.a. inflation. On this basis, maintenance costs developed for TAV are comparable with Belgium, France, and Spain within the context of a feasibility study.

3.3.7 It should be noted that the allocation of operating costs into the headings shown in Table 3-4 is by no means a straightforward exercise and depends heavily on the management accountancy system used by each railway administration, as noted by the authors of the research paper. Other researchers have also commented on the opaqueness and limited disclosure of railway operating costs,[13] and the difficulty of comparison between railway administrations, as there are no management accountancy standards, or standardised methodologies for the collation of railway maintenance costs. The methodology used here assumes a fixed cost per km rather than a per train km basis as a large proportion of track, electrification and signalling and telecommunication maintenance costs are fixed. Maintenance costs will obviously vary depending on the level of traffic intensity and the values adopted reflect average to heavy usage.

3.3.8 Table 3-4 shows '-' for some categories e.g. telecommunications is shown as '-' for France. However, this does not mean that no costs are incurred for telecommunications but instead these costs are probably categorised under signalling because these items are treated together in French railway accounts. As discussed in Volume 5, there are similar problems when comparing unit costs estimates to ensure that comparisons are made on a 'like-for-like' basis.

3.3.9 Despite the fact that the allocation of maintenance costs differs between railway administrations, Belgium, Spain and France have average costs in the region €40k to €47k per km, with the estimated value for TAV at €46k per km based on the methodology set out in this report. This gives confidence that at an average cost per km, the rates derived for TAV are consistent with international benchmarks, even if the proportion of costs may vary.

[12] **Campos, de Rus, and Barron (2006)** Some stylized facts about high speed rail around the world: an empirical approach. 4th Annual Conference on Railroad Industry Structure, Competition and Investment**,** Universidad Carlos III de madrid, October 19-21 2006;

Table 3-4: Cost of Infrastructure Maintenance by Country (2002/2009 prices, €/ track km)

	Belgium	France	Italy	Netherlands	Spain	TAV(1)
Track Maintenance	13,841	26,524	5,941	37,213	13,531	27,203
Electrification	2,576	3,895	2,455	7,165	2,986	9,100
Signalling	3,248	7,185	4,522	11,942	8,654	9,851
Telecommunications	1,197	-	-	-	5,637	-
Other Costs	10,821	-	-	14,330	2,650	-
Total Maintenance cost	31,683	37,604	12,919	71,650	33,457	-
Inflated to 2009 prices	**40,237**	**47,757**	**16,407**	**90,995**	**42,490**	**46,154**
(1) 2009 prices from GBP£ to € using 1.19 i.e. £22.8k = €27.203k						

Profiling of Permanent Way Costs

3.3.10 Maintenance costs for permanent way have been profiled to reflect the fact assets will be new and will initially require minimal maintenance. However, over time it is reasonable to assume maintenance costs will increase and ultimately assets will require replacement. Profiling of maintenance costs has been done as follows:

- based on the estimated annual maintenance costs given in the tables above a total cost over 40-years was calculated;
- 10% of the total 40-year cost is assumed to be spent between 2014 and 2024. i.e. 1% of the 40-year total is spent in 2014 until 2024;
- 30% of the total 40-year cost is assumed to be spent between 2024 and 2034 i.e. 3% of the 40-year total is spend in 2024 until 2024; and
- 60% of the total 40-year cost is assumed to be spent between 2034 and 2044 i.e. 6% of the 40-year total is spent in 2034 until 2044.

3.3.11 The profile of maintenance costs reduces costs significantly in the first 10-years of operation, but as a result they are much higher in later years as the assets require more maintenance. Table 3-5 shows the Permanent Way maintenance costs for 2014.

Table 3-5: 2014 Profiled Maintenance Costs

	Source	Cost (R$ k)
Track Maintenance	HALCROW	R$ 87,1m
Electrification	HALCROW	R$ 29,1m
Signalling & Telecommunications	HALCROW	R$ 31,5m
Total Permanent Way		**R$ 147,7m**

[13] **Steer Davis Gleave (2006),** Air and Rail Competition and Complementarity. Prepared for European Commission DG TREN.

3.4 Maintenance of Structures

3.4.1 Estimating maintenance costs for railway structures is even more problematic than for Permanent Way. For this reason, the values given here are based on an adaptation of rates supplied by PROMPT ENGENHARIA LTDA for tunnels, earthworks and bridges to reflect recent Brazilian details. Full details of PROMPT ENGENHARIA LTDA's work are given in Appendix B.

3.4.2 A value of 3% of capital cost was adopted for station maintenance based PROMPT's analysis. A wide range of maintenance costs are possible for stations depending on their final specification and layout.

3.4.3 Details are given in Table 3-6 below.

Table 3-6: Maintenance of Structures

	Source	Quantity	Rate	Cost (R$ per year)
Earthworks & Drainage	PROMPT	301.6 km	40,204.7 R$/km	R$ 12.1m
Tunnels	PROMPT	91.0 km	19,536.6 R$/km	R$ 1.8m
Bridges	PROMPT	1.50 million m^2	11.57 R$/$m^2$	R$ 17.3m
Stations	PROMPT	8 stations	3% of Capital Cost (R$710m)	R$ 21.3m
Total Structures				**R$ 52,6m**

3.4.4 Tunnels are expensive to maintenance because of the more onerous mechanical and electrical systems required for safety. One consideration for bidders will be the use of slab track in tunnels which is initially more expensive but has lower maintenance costs. Other considerations include the installation of remote monitoring equipment but this obviously has a higher initial cost.

3.5 Train and Customer Service

3.5.1 Staff costs were estimated for the various departments of the new railway organisation, from senior management, administration & finance, marketing & revenue, train & infrastructure maintenance, and train operations & control. The estimates are based on local Brazilian labour costs. Appropriate social security costs and salary enhancements were added to obtain the total labour costs. These are set out in Table 3-7 below.

3.5.2 Train crew numbers are based on the number of train services and hours of operation taking into account productivity. International standards for the crewing of trains also vary and some countries require two drivers per cab for high speed running. It is assumed that four people are required for an 8-car train and six for a 16-car train. Train crew and rolling stock maintenance staff costs are assumed to increase in line with train Km.

3.6 Rolling Stock Maintenance

Train Maintenance

3.6.1 As Brazil currently does not operate any comparable high speed services rolling stock maintenance costs are based on international costs of maintaining modern high speed rolling stock. As with infrastructure maintenance, rolling stock costs can vary depending on underlying assumptions and the category of costs, e.g. light/heavy maintenance. In the UK and elsewhere in Europe, the trend is for train manufacturers to supply both trains and maintenance together in a single contract. This type of contract requires the train manufacturer to build maintenance depots and directly employ maintenance staff.

Table 3-7: 2014 Annual Staff Costs

Staff Costs	Source	Staff Numbers	Cost (R$ per year)
Management Staff/Directors	PROMPT	20	R$ 3.7m
Train Crew	PROMPT	264	R$ 8.9m
Maintenance Staff (Rolling Stock and Track)	HALCROW	87	R$ 8.7m
Other Staff		251	R$ 12.8m
Administration and Finance	*PROMPT*	*52*	*R$ 2.6m*
Train Formation and Availability	*HALCROW*	*37*	*R$ 3.5m*
Stations and CTC	*PROMPT*	*162*	*R$ 6.6m*
Total Staff		**542**	**R$ 34.1m**

3.6.2 The big advantage of the above scheme is the management of performance risk. Under these contracts, manufacturers are required to take the performance risk of the train fleet, which is linked to a performance regime. The performance regime typically measures, inter alia, the number of breakdowns or failures in service per train km, and the number of sets available for daily service against the planned timetable. It is also worth noting that during the initial years of operation considerable effort will be needed to manage the high speed train fleet, as experience shows that new train fleets often require time to "bed down" in service. Given that the winning consortium will likely include a train manufacturer, this type of contract could be considered.

3.6.3 Train maintenance costs presented here are based on international rates and were factored to reflect lower overall costs in Brazil. The average cost per km was estimated at R$ 6.6 per train kilometre. The recent research paper quoted earlier cites an average cost per km of €2 (2006 prices) which is equivalent to R$ 5.8 per km, close to the value recommended here when adjusted for inflation. The research paper also notes that trains maintenance costs vary depending on usage, maintenance plans and periodicity of refurbishment.

3.6.4 The annual number of train kilometres travelled is an output of the train planning work using VoyagerPlan (as explained in Chapter 2). Table 3-8 below shows a summary of the traction & rolling stock annual maintenance cost.

Table 3-8: Traction & Rolling Stock Annual Maintenance

Rolling Stock	Source	Unit Rate	Quantity	Cost (R$ per year)
Rolling stock maintenance	HALCROW	R$ 6.6 per train Km	26,421,927	R$ 174.2m
Rolling stock traction power	PROMPT	R$ 0.14 per kWh	245,804,670 kWh	R$ 34.4m
Rescue Locomotives	HALCROW	2% of purchase price	Purchase price R$ 62.1m	R$ 1.2m
Total Rolling Stock				**R$ 209.9m**

3.6.5 The train km/per year assumes the whole network will open at once and not be phased. The cost of operating the three rescue locomotives is estimated at 2% per annum of their capital cost.

Train Electrical Energy

3.6.6 Traction electricity cost requires a detailed analysis to estimate the expected energy consumption required to move the trains. Based on international experience, there are normally peak charges in energy costs by time of day, throughout the week, and by time of year. Some initial work was done to simulate traction power consumption to provide a reasonable estimate based on Railsys outputs.

3.6.7 As the new trains will incorporate regenerative braking which can be used while trains are coasting downhill, the consumption rates were factored down (by 16.5%) to reflect the benefits of this. The following Tables (Table 3-9, Table 3-10, Table 3-11, Table 3-11, and Table 3-12) show energy consumption simulated in RailSys for 300km/h operation as the basis for estimating electricity consumption.

Table 3-9: Energy Consuption - Barão de Mauá to Campinas

Station	Applied work kWh	Cost R$ (R$0.14 kWh)
Barão de Mauá (RJ)	0.00	0.00
Galeão	310.20	43.43
Barra Mansa/Volta Redonda	1,834.30	256.80
Sao Jose dos Campos	4,261.70	596.64
Guarulhos Airport (SP)	5,227.20	731.81
Campo de Marte (SP)	5,590.00	782.60
Viracopos Airport	7,024.70	983.46
Campinas	7,413.00	1037.82

Table 3-10: Energy Consumption - Campinas to Barão de Mauá

Station	Applied work kWh	Cost R$ (R$0.14 kWh)
Campinas	0.00	0
Viracopos Airport	327.70	45.88
Campo de Marte (SP)	1,471.60	206.02
Guarulhos Airport (SP)	1,880.50	263.27
Sao Jose dos Campos	2,764.80	387.07
Barra Mansa/Volta Redonda	4,785.20	669.93
Galeão	5,822.70	815.18
Barão de Mauá (RJ)	6,118.50	856.59

Table 3-11: Energy Consumption - Barão de Mauá to Campo de Marte (Non-Stop)

Station	Applied work kWh	Cost R$ (R$0.14 kWh)
Barão de Mauá (RJ)	0.00	0
Campo de Marte (SP)	4,687.00	656.18

Table 3-12: Energy Consumption - Campo de Marte to Barão de Mauá (Non-Stop)

Station	Applied work kWh	Cost R$ (R$0.14 kWh)
Campo de Marte (SP)	451.40	0
Barão de Mauá (RJ)	4,315.60	604.18

3.6.8 The unit cost of energy consumption (R$ 0.14 per KW Hour) was taken from PROMPT ENGENHARIA LTDA's work and the total cost of energy consumption was estimated at R$ 34.4 million in 2014 by PROMPT.

3.7 Complementary Costs

3.7.1 An allowance has been included for sales and marketing at 0.88% p.a. of gross revenues based on international experience. A further R$ 1.6 million was added for utilities at offices and other expenses based on analysis undertaken by PROMPT ENGENHARIA LTDA. Details are given in Table 3-13.

Table 3-13: Complementary Costs

Complementary Costs	Source	Unit	Cost (R$ per year)
Sales and Marketing	PROMPT	0.88 % of gross revenue	R$ 21.3m
Utilities	PROMPT	Office buildings	R$ 1.6m
Total Rolling Stock			**R$ 22.9m**

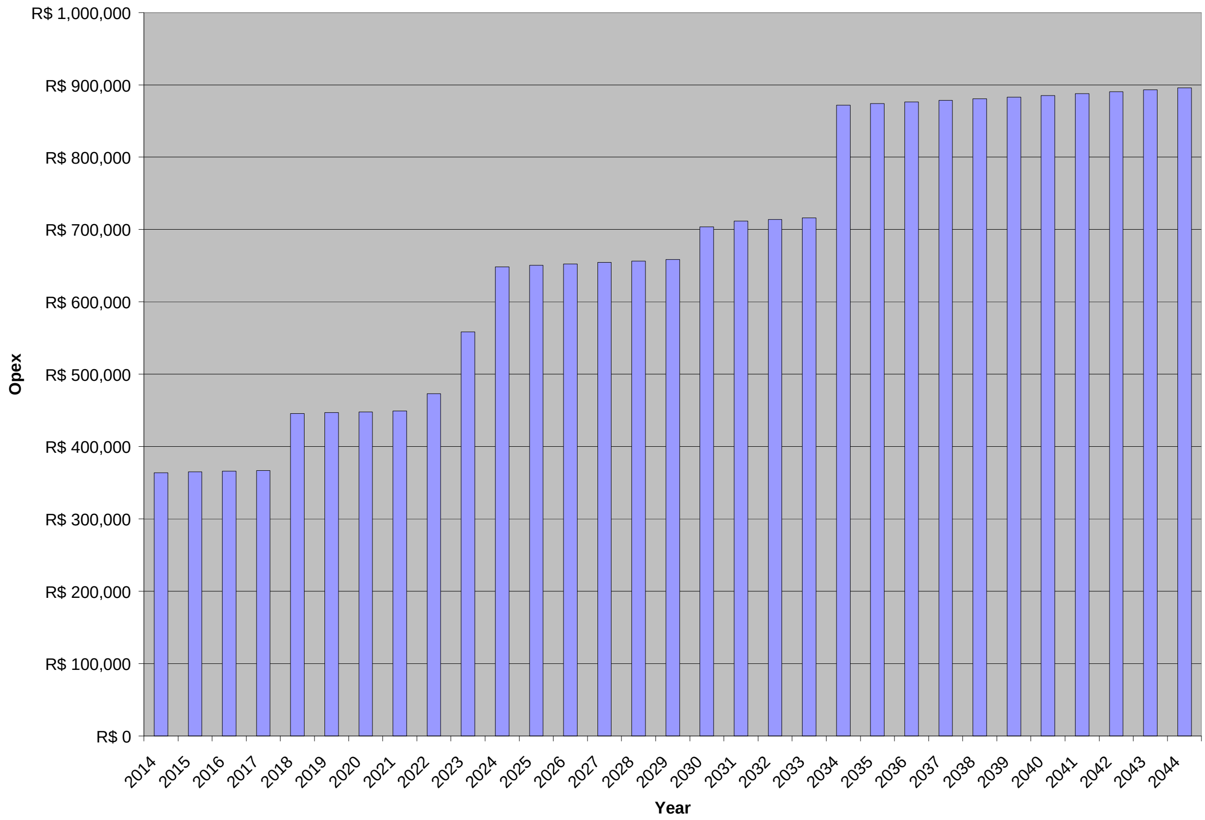
3.8 Opex Summary

3.8.1 Table 3-14 provides a summary of Opex costs expected for 2014, 2024, 2034 and 2044, while Figure 3-1 shows the profile of costs between 2014 and 2044. All prices are constant in real terms and no account has been taken of inflation.

Table 3-14: Summary of Opex, 2014, 2024, 2034 and 2044 R$k

Cost	2014	2024	2034	2044
Permanent Way				
Track	R$ 26,128	R$ 78,383	R$ 156,766	R$ 156,766
Electrification	R$ 8,741	R$ 26,222	R$ 52,445	R$ 52,445
Signalling/Telecoms	R$ 9,462	R$ 28,386	R$ 56,772	R$ 56,772
sub-total	**R$ 44,331**	**R$ 132,992**	**R$ 265,983**	**R$ 265,983**
Infrastructure				
Earthworks	R$ 12,127	R$ 12,127	R$ 12,127	R$ 12,127
Tunnels	R$ 1,778	R$ 1,778	R$ 1,778	R$ 1,778
Bridges	R$ 17,354	R$ 17,354	R$ 38,315	R$ 38,315
Stations	R$ 21,300	R$ 21,300	R$ 21,300	R$ 21,300
sub-total	**R$ 52,559**	**R$ 52,559**	**R$ 73,520**	**R$ 73,520**
Staff Costs				
Management	R$ 3,773	R$ 3,773	R$ 3,773	R$ 3,773
Train Crew	R$ 8,881	R$ 12,314	R$ 13,153	R$ 13,153
Maintenance	R$ 8,683	R$ 13,876	R$ 15,430	R$ 15,482
Staff Other	R$ 12,786	R$ 12,786	R$ 12,786	R$ 12,786
sub-total	**R$ 34,124**	**R$ 42,750**	**R$ 45,143**	**R$ 45,195**
Rolling Stock Maintenance				
Express/Regional	R$ 174,230	R$ 316,224	R$ 358,697	R$ 360,119
Traction Power Cost	R$ 34,413	R$ 68,825	R$ 73,741	R$ 73,741
Locomotives	R$ 1,242	R$ 1,242	R$ 1,242	R$ 1,242
sub-total	**R$ 209,884**	**R$ 386,291**	**R$ 433,680**	**R$ 435,102**
Complementary Costs				
Utilities	R$ 1,665	R$ 1,665	R$ 1,665	R$ 1,665
Sales & Marketing	R$ 21,308	R$ 32,263	R$ 52,107	R$ 74,215
sub-total	**R$ 22,973**	**R$ 33,928**	**R$ 53,771**	**R$ 75,879**
Total Operating Costs	**R$ 363,871**	**R$ 648,519**	**R$ 872,097**	**R$ 895,679**

Figure 3-1: Opex Profile 2014 – 2034 (R$ k Constant)



Appendix A: Guarulhos Airport Technical Note

Appendix B: PROMPT Engenharia OPEX Analysis